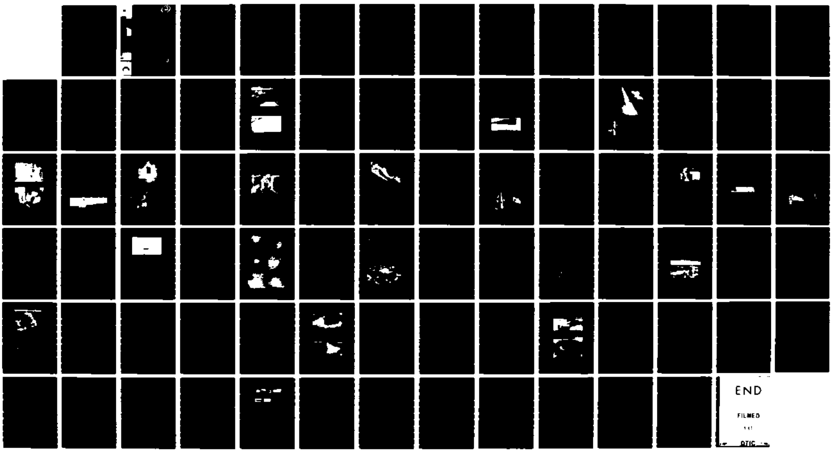
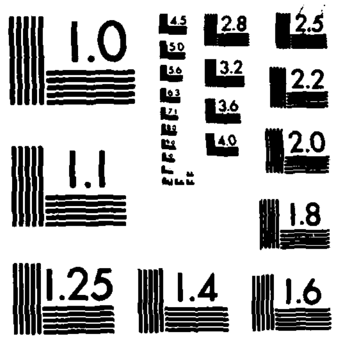
AD-A131 187 EXPLOSIVE DITCHING AND PAVEMENT BREACHING TESTS AT YUMA PROVING GROUND 19.. (U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUC.. 1/1

UNCLASSIFIED G A WOODBURY ET AL. JUN 83 WES/MP/SL-83-10 F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

US Army Corps of Engineers

AD A131187

MISCELLANEOUS PAPER SL-83-10

2

EXPLOSIVE DITCHING AND PAVEMENT BREACHING TESTS AT YUMA PROVING GROUND, 1978-1980

by

George A. Woodbury, Jeremiah J. Sullivan, Allen D. Rooke, Jr.

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

June 1983

Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project No. 4A762719AT40

STRUCTURES LABORATORY

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Miscellaneous Paper SL-83-10

2. GOVT ACCESSION NO.
AD-A131187

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
EXPLOSIVE DITCHING AND PAVEMENT BREACHING TESTS AT YUMA PROVING GROUND, 1978-1980

5. TYPE OF REPORT & PERIOD COVERED
Final report
September 1978-January 1980

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
George A. Woodbury
Jeremiah J. Sullivan
Allen D. Rooke, Jr.

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Structures Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Project
4A762719AT40

11. CONTROLLING OFFICE NAME AND ADDRESS
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE
June 1983

13. NUMBER OF PAGES
74

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Antitank obstacles
Blasting agent
Cratering
Ditching
Line charges
Pavement breaching
Roadway demolition
Shaped charges
Slurry

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Beginning in FY 1975, the U. S. Army Engineer Waterways Experiment Station (WES) assumed management of a Corps of Engineers research program for Military Engineering Applications of Commercial Explosives (MEACE). In early 1977, the Army Materiel Development and Readiness Command initiated a program to standardize a blasting agent for Army use and identified a pumpable slurry for standardization tests. The slurry blasting agent selected, IRECO DBA-105P, packaged as a binary explosive for military use, was officially designated (August 1978) as

(Continued)

20. ABSTRACT (Continued).

Demolition Kit, Blasting, XM268. The most significant doctrinal application to be investigated in the test program was the creation of antiarmor ditches by detonating buried slurry-filled plastic pipe.

This report describes ditching tests using buried, slurry-filled pipe at Yuma Proving Ground (YPG). Problems of pipe emplacement, pumping, and slurry priming (or boostering) in the filled pipes were studied. Ditching in a desert soil of known poor cratering capability, representing a likely "worst case" cratering condition (by soil type), was assessed. A method of station pumping was tested and detonation velocity measured to assess the feasibility of employing the slurry in very long pipes. Pavement breaching application was tested in pipe buried 5 ft beneath a concrete pavement constructed to simulate a West German autobahn. Pavement penetration tests using the 15-lb M2A3 shaped charge and pavement breaching tests using the M180 demolition (cratering) kit were conducted. (Tests with pipe buried in other types of soil and a more general comparison of TNT and DBA-105P cratering in various soils are presented in a companion report.)

The Yuma test demonstrates that previously buried 600-ft lengths of 4-in.-diam PVC pipe may be pumped full with DBA-105P and detonated from one end, producing antiarmor ditches upon order. It is concluded that employment of the pumpable XM268 in preemplaced long pipes is a workable concept and that successful application in pavement breaching (paved roadway ditching) appears highly probable. Problem areas requiring further research are identified.

PREFACE

This study was sponsored by the Office, Chief of Engineers, as part of the Military Engineering Applications of Commercial Explosives (MEACE) program under Project 4A762719AT40, "Mobility and Weapons Effects Technology." The Yuma Proving Ground (YPG) test was the culmination of a series of MEACE tests designed to evaluate the effectiveness of antiarmor ditches formed by the detonation of blasting agent pumped into buried plastic pipe.

This test was planned, coordinated, and executed by MAJ G. A. Woodbury, with the assistance of Mr. F. W. Skinner. Assisting in the planning and coordination at YPG were Messrs. Larry Nemecek and Wayne Taylor. The Commander of YPG was COL Leon K. Davis. Assisting in the arrangements for the M180 Cratering Kits from the U. S. Army Armament Research and Development Command (ARRADCOM) were Mr. Ted Wheller, MAJ Robert Eschenbaum, and Mr. Frank Vrabel. Assisting in the execution of the test were soldiers from Company A, Communications Equipment Installation Battalion, Ft. Huachuca, under the command of SSG Mike Gomez. Commander of A Company was CPT Henry Allen. Personnel of the U. S. Army Engineer Waterways Experiment Station (WES) assisting in the YPG test were Mr. C. E. Green, Geotechnical Laboratory, and Messrs. S. B. Price and William Washington, Structures Laboratory (SL).

Project Officer for the MEACE program was Mr. H. D. Carleton. The study was conducted under the general supervision of Mr. L. F. Ingram, Chief, Explosion Effects Division (EED), SL, and upon Mr. Ingram's retirement, Messrs. J. L. Drake and J. D. Day, Acting Chiefs, EED. Also providing general supervision was Mr. Bryant Mather, Chief, SL. This report was prepared by MAJ Woodbury and Messrs. J. J. Sullivan and A. D. Rooke, Jr., of EED.

Commanders and Directors of WES during the conduct of the test and preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02832	cubic metres
cubic feet per minute	0.0004719	cubic metres per second
cubic yards	0.7646	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (U. S. liquid)	0.003785	cubic metres
grains	0.00006480	kilograms
inches	25.4	millimetres
miles (U. S. statute)	1.609	kilometres
ounces (mass)	0.02835	kilograms
pounds (force) per square inch	6.895	kilopascals
pounds (mass)	0.4536	kilograms
pounds (mass) per cubic foot	16.02	kilograms per cubic metre
pounds (mass) per foot	1.488	kilograms per metre
pounds (mass) per minute	0.007560	kilograms per second

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

EXPLOSIVE DITCHING AND PAVEMENT BREACHING TESTS AT YUMA PROVING GROUND, 1978-1980

PART I: INTRODUCTION

Background

1. In August 1977, the U. S. Army Engineer Waterways Experiment Station (WES) was tasked by the Office, Chief of Engineers, Research and Development Office (DAEN-RD), to evaluate a Concept Evaluation Proposal from the U. S. Army Engineer School. The objective as stated in the proposal was "to determine if filling rapidly buried pipe of various diameters with a blasting agent and then detonating it will create effective antitank ditches." The specific item to be tested was polyvinyl chloride (PVC) plastic pipe filled with a blasting agent manufactured by IRECO Chemicals, Inc., of Salt Lake City, Utah, under the commercial name DBA-105P (Dense Blasting Agent No. 105, Pourable). For military application, DBA-105P is packaged as Demolition Kit, Blasting, XM268, a binary explosive consisting of two nonexplosive components, a liquid and a powder, which can be mechanically or manually mixed to produce a pumpable, explosive slurry. Further details concerning development and composition of the XM268 kit are given in Appendix A. The blasting agent (BA) was undergoing standardization trials conducted by the U. S. Army Test and Evaluation Command (TECOM), Aberdeen Proving Ground, Md., with WES assisting TECOM under the Military Engineering Applications of Commercial Explosives (MEACE) program by testing applications and preparing accompanying doctrine for use of the blasting agent. These tests by TECOM and WES demonstrated the superior cratering performance in soils of DBA-105P compared with TNT and the ammonium nitrate-based military cratering charge (Carlton, Sullivan, and Rooke 1983; Scheider and Daneker 1980; Woody and Coleman 1980).

2. Testing of the buried pipe concept began in December 1977 at the WES Big Bl ıck Test S te, followed by additional pipe shots at a site

near Warsaw, Mo., in May 1978 (Carleton, Sullivan, and Rooke 1983). These tests served to narrow the practical choices on some emplacement parameters; i.e., pipe size, burial depth, filling technique, and priming and detonating. Additional tests were needed in a dry soil, both to determine ditch dimensions in a dry soil and to refine emplacement techniques. A survey of possible test sites led to the selection of Yuma Proving Ground (YPG), Ariz.

3. Concurrently with interest in reduction of armor cross-country mobility, questions were raised regarding the applicability of the BA to creating ditch obstacles in highways, such as the Federal Republic of Germany (GE) autobahn system. The decision was made to include in the YPG tests a replica of the autobahn with buried plastic pipes emplaced for loading and firing.

4. As test planning progressed, WES was asked by DAEN-RD to include an evaluation of the M180 Cratering Kit on the "autobahn," and the test plan was duly expanded to do this and to compare this device to other explosives in a single-charge cratering role.

5. The original plan called for the field work to be accomplished in September 1978. Site preparations proceeded on this schedule, and the long-pipe arrays (cross-country countermobility) and autobahn roadway sections were prepared. Problems with the blasting agent, discussed in Appendix A, forced the postponement of the 1978 tests after only one ditching event had been successfully fired; field work was not resumed (and completed) until January 1980. By this time, minor changes in test objectives and layouts had been instituted.

YPG Test Scope and Objectives

Pipe tests

6. The pipe tests consisted of different lengths and configurations of buried 4-in.-diam* PVC pipe filled with BA:

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

a. Two separate 600-ft-long pipes.

b. Three separate 100-ft pipes.

c. A double ditch event consisting of two parallel, 60-ft pipes at 40-ft separation (conducted in 1978).

d. A double pipe (adjacent parallel pipes) under the simulated autobahn.

e. Three 10-ft pipe sections.

7. The 600-ft pipe shots were to provide the following information:

a. Detonation velocity profiles of the BA in buried 4-in. plastic pipes.

b. Preliminary data on pumping pressures, rates, and problems associated with long 4-in.-diam pipe sections.

c. An evaluation of a station pumping concept, which would permit pumping long sections of pipe while maintaining low pumping pressures by moving to successive pumping stations as necessary.

8. The 100-ft-long pipes were to be primed or boostered* using several different techniques to evaluate effects on ditch dimensions. The double 60-ft pipe shot in 1978 was to test an antiarmor ditching design. The double pipe array under the autobahn was planned to evaluate the pavement breaching applications of the buried plastic pipe. The short, 10-ft sections were to test methods of boostering the blasting agent by the use of detonating cord. Table 1 lists all shots conducted in this study except those with the 10-ft pipes, which were evaluated on a qualitative basis only.

M180 Cratering Kit tests

9. Shaped charges were fired on the simulated autobahn pavement to determine an optimum standoff distance for the shaped charge component of the M180 Cratering Kit; the shaped charge opens an entry hole for the M180 rocket. One shaped charge hole was filled with BA, which was detonated as an expedient roadway cratering charge.

---

* Blasting agents are, by definition, not cap-sensitive; i.e. they cannot be detonated by ordinary (up through size No. 8) blasting caps. Because of their insensitivity, blasting agents should be detonated by a primer or booster of high explosives (HE).

Table 1

Demolition Test Schedule

Shot Designation	Description	Date	Remarks
6SDR1	Two parallel 4-in. pipes, 60 ft long (40-ft center-line separation)	26 Sep 78	
6SR1	Single 4-in., 600-ft pipe	Scheduled Sep 78	Not fired; BA problem
6SR2	Single 3-in., 600-ft pipe	Scheduled Sep 78	Not fired; BA problem
6HC1	Single 4-in. pipe under pavement	Oct 79	Incomplete detonation
6HC2	Double 4-in. pipe under pavement	Oct 79	Incomplete detonation
6SC1	15-lb shaped charge on 8-in. pavement	14 Jan 80	
6SC2	15-lb shaped charge on 12-in. pavement	14 Jan 80	
6SC3	15-lb shaped charge on 8-in. pavement	14 Jan 80	
6SC4	15-lb shaped charge on 12-in. pavement	14 Jan 80	
6SC5	15-lb shaped charge on 8-in. pavement	14 Jan 80	
6SC6	15-lb shaped charge on 12-in. pavement	14 Jan 80	
6CK1	M180 on 8-in. pavement	14 Jan 80	
6CK2	M180 on soil	14 Jan 80	
6CK3	M180 on 12-in. pavement	15 Jan 80	Malfunction
6CK4	M180 on 12-in. pavement	15 Jan 80	
6CK5	M180 on 12-in. pavement	15 Jan 80	Malfunction
6CK5A	Detonation of 6CK5 warhead by TNT	15 Jan 80	
6RC3	Triple 4-in. pipe under pavement	15 Jan 80	Only 2 pipes were loaded and fired
6SR1A	Single 4-in., 100-ft pipe boostered both ends	16 Jan 80	One booster failed(?)
6SR1B	Single 4-in., 100-ft pipe boostered both ends	18 Jan 80	
6SR4A	Single 4-in., 100-ft pipe with 4 strands of detonating cord	21 Jan 80	
6SR5	Single 4-in., 600-ft pipe	21 Jan 80	
6SR3	Single 4-in., 600-ft pipe	22 Jan 80	
6SC7	15-lb shaped charge perpendicular to 12-in. pavement	22 Jan 80	
6BA1	BA in shaped charge hole through 12-in. pavement	22 Jan 80	

10. Five M180 Cratering Kits were available. The test objectives for this munition were to:

a. Evaluate the concrete penetration performance of the shaped charge portion of the kit.

b. Evaluate the pavement breaching and cratering performance of the kit on the simulated GE autobahn.

c. Compare the cratering performance of the kit in desert soil to prior test results of preemplaced 40-lb, BA cratering charges.

A description of the M180 Cratering Kit is given in Appendix B; detailed operational characteristics and maintenance information are furnished in Draft Technical Manual 9-1375-213-12-1 (Headquarters, Department of the Army 1979).

PART II: DESCRIPTION OF THE TEST

Test Sites

11. The test series was divided into two phases, each conducted at a different YPG site. The autobahn breaching and cratering tests were conducted at a site in the Kofa Range area. The remaining pipe tests were conducted in the North Cibola Lake Range area. Figures 1-3 show these sites. Both sites were typical southwestern U. S. desert, characterized by "desert pavement"* and sparse vegetation. Soil classifications at North Cibola ranged from near-surface sandy silty gravel (GM)** to sandy clay (CH)** at a depth of about 20 ft. A stratum of calcareous material--possibly caliche--lay about 2 ft below the surface. Dry density at the surface was about 86 lb/ft^3, becoming somewhat greater with depth. Moisture content was on the order of 3 percent.

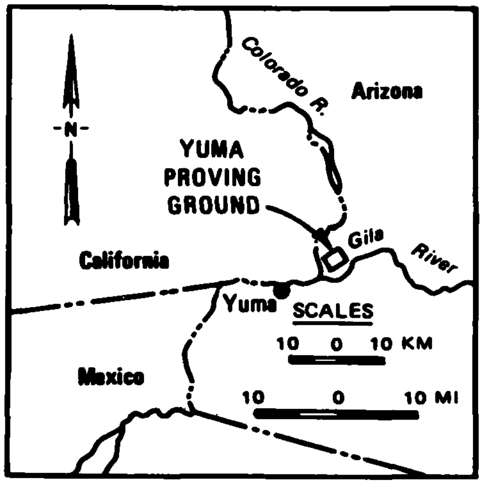


Figure 1. Vicinity map

Site Preparations

Kofa Range site

12. The autobahn pavement design was based upon "Technical Specifications and Rules for the Construction of Concrete Road Surfaces, Streets and Autobahns," provided to WES by GE. Of six possible designs, the strongest was selected. This design called for 8.66 in. of 4900-psi concrete. For concrete of this thickness, no reinforcement is

---

* Surface layer is of gravel-size igneous material resulting from wind erosion of finer, surrounding material. It does not withstand repeated vehicular passages.

** Classification according to the Unified Soil Classification System (Office, Chief of Engineers 1968).

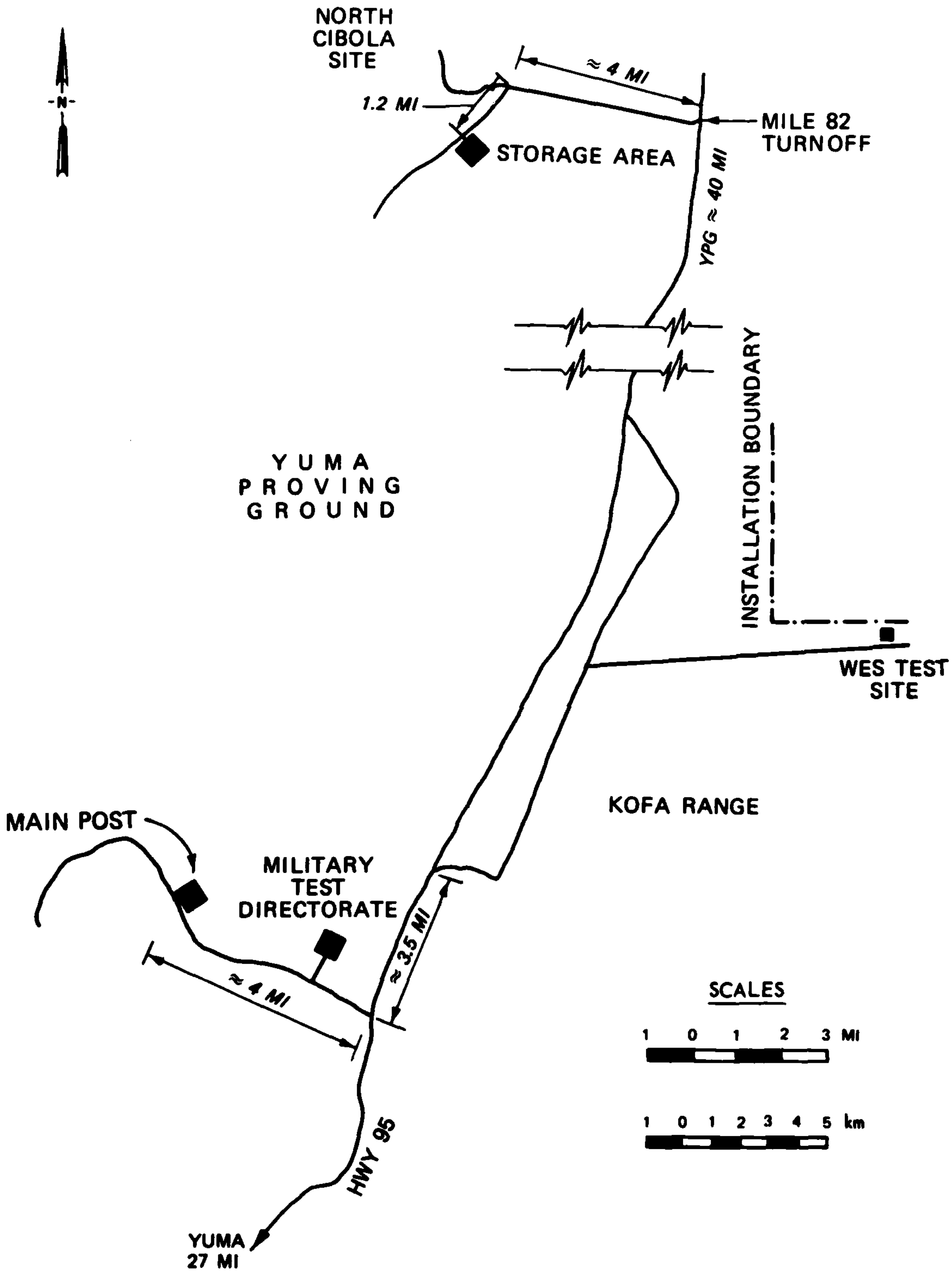


Figure 2. Site map, North Cibola and Kofa Range test sites, YPG

a. Overview of North Cibola test site showing long-pipe array

b. Autobahn test site on Kofa Range

Figure 3. Test sites at YPG

required. Dummy joints greater than 25 percent and less than 30 percent of slab thickness were to be cut every 24 ft. The specifications called for a base course consisting of 3.9 in. of asphalt pavement, or 5.9 in. of soil cement, or 5.9 in. of compacted bituminous-treated soil; however, cost limitations prevented the preparation of a base course. Overall pavement dimensions were to be 300 by 24 ft. The first 40-ft section was formed for a thickness of 8-1/2 in. To compensate for the lack of a base course, an additional 3-1/2 in. of concrete thickness was included in the remaining 260-ft section. Thus, two distinct design thicknesses, 8-1/2 and 12 in., intended to represent two extremes in resistance to cratering, were to be made available for testing.

13. The long distance to the concrete mixing plant, combined with the 110°F and greater heat, caused the concrete to set very rapidly in spite of the addition of admixtures to retard curing and increase workability. The initial batches which went into the 8-1/2-in.-thick section were much too stiff to be workable. As a result, the first section had a reverse crown; the outside was 8-1/2 in. thick, but the center was only 7-1/2 in. thick.* In subsequent batches, 600 lb of ice was added in lieu of the equivalent amount of water to retard set time. To improve workability, additional water was added and concrete content was increased; 7.6 bags of Type II cement** were used per cubic yard of concrete.

14. To monitor strength of the set concrete, two standard 6-in. concrete cylinder samples were obtained from each delivery truckload. After 28 days (29 days for the first day's pour), one cylinder from each truckload was tested for compressive strength. (Type II cement

---

* The average thickness of 8 in. is used throughout the remainder of the text in referring to tests on this 40-ft section. For simplicity, the 260-ft section with a center thickness of about 11-1/2 in. will be referred to throughout by its design thickness of approximately 12 in.

** Portland cement especially made for pouring of heavy concrete sections in warm weather. A bag weighs 94 lb. The amount used in this mix is an approximate maximum for a 3-in. slump, a measure of stiffness. This slump represents a recommended practice for forming of pavement. A maximum of 38 gal of water per cubic yard should have been used, but this was probably exceeded.

achieves approximately 75 percent of its full strength in 28 days.) The remaining cylinders were tested after the pavement breaching tests were complete. Results of both tests are presented in Table 2. As can be seen, neither sample set achieved the desired 4900-psi strength. This result is attributed to excessive water in the mix and to rapid curing induced by the high temperatures.

15. After placement, the concrete was coated with a liquid curing compound and the dummy joints were cut on 24-ft centers, to the required

Table 2

Concrete Cylinder Test Results

Sample No.	Age days	Compressive Strength psi	Sample No.	Age days	Compressive Strength psi
1-1	29	3803	2-1	639	2480
1-2	29	2936	2-2	639	3300
1-3	29	3449	2-3	639	3710
1-4	29	3767	2-4	639	4190
1-5	29	3272	2-5	639	3360
1-6	29	3192	2-6	639	3380
1-7	29	3051	2-7	639	3310
1-8	29	3440	2-8	639	3800
1-9	29	3182	2-9	639	3250
1-10	28	3520	2-10	638	3820
1-11	28	3520	2-11	638	4050
1-12	28	3431	2-12	638	4030
1-13	28	3024	2-13	638	3550
1-14	28	3626	2-14	638	3870
1-15	28	3007	2-15	638	3820
1-16	28	3281	2-16	638	3540
1-17	28	3467	2-17	638	3800
1-18	28	3405	2-18	638	3250
1-19	28	3414	2-19	638	3590
1-20	28	3626	2-20	638	4240
1-21	28	3820	2-21	638	4370
1-22	28	3007	2-22	638	3700
1-23	28	3484	2-23	638	3640
1-24	28	3431	2-24	638	4330
Range		= 2936 - 3820	Range		= 2480 - 4370
Mean		= 3381	Mean		= 3682
Standard Deviation		= 257.3	Standard Deviation		= 425.6

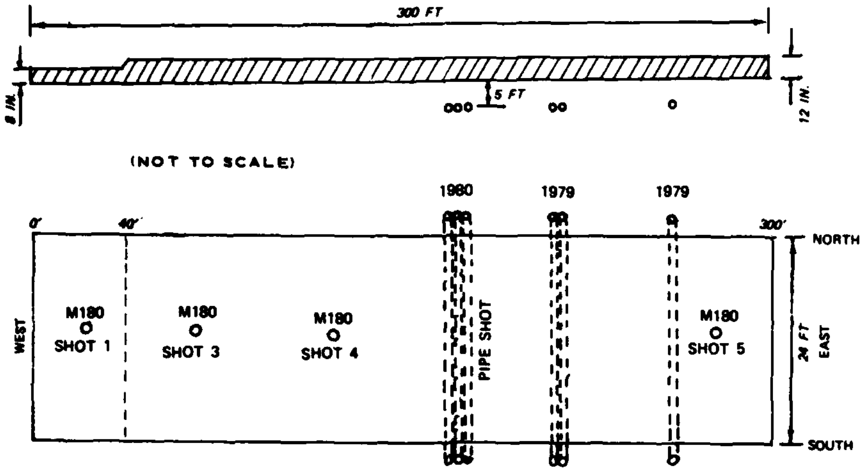
depth, with a concrete saw. The sample cylinders were left on the site for 7 days and then returned to WES for steam room storage. An interval of approximately 15-1/2 months separated the construction of the autobahn and the pavement breaching tests in January 1980. Based upon linear interpolation between the 28-/29-day and the 638-/639-day compressive strengths in Table 2, concrete strength at the time of explosive testing should have averaged about 3600 psi.

16. The 4-in.-diam Schedule 40 PVC pipes were preemplaced beneath the roadway prior to the setting of the formwork. The emplacement trenches were dug with a backhoe using a 24-in.-wide bucket, and the pipes, each of 30-ft length, were assembled in the trench. The glue used to assemble the pipe lengths was allowed to cure from 1 to 2 hours prior to backfilling. The standpipes were covered to keep out dust and moisture until the pipes were needed. Figure 4 illustrates the autobahn construction and the pipe emplacements.

North Cibola site

17. The North Cibola Lake site had been laid out for four 600-ft-long pipes in 1978. However, the September 1978 long-pipe shots were postponed due to problems with the blasting agent,* leaving some 450 ft of buried 4-in. pipe in place (6SR1), a 600-ft open trench (6SR4), and approximately 1200 ft of 4-in. PVC pipe in storage. In January 1980, the site and stored pipe were found to be in good condition, simplifying the task of site rehabilitation. The in-place pipe (6SR1) was excavated at appropriate intervals and cut, and the required fittings were added to allow two 100-ft sections to be used to test alternative boostering techniques. A third 100-ft-long, 4-in.-diam pipe was placed in the north end of trench 6SR4, excavated for the 1978 test. These and other

* Investigation revealed that the aluminum particulate in the blasting agent had been contaminated with magnesium (see Appendix A). The problems encountered in field use were duly reported ("Summary Report: Problems Encountered with DBA-105P at Yuma, AZ, 18-29 September 1978," WES letter report, Feb 1979) and will not be further discussed here. The XM268 field mix kit was used in the 1978 test; the slurry provided for the 1980 Yuma test was mixed and bagged at the factory. The tests in October 1979 which involved WES in a support role to YPG (paragraph 21) employed the newly reformulated field mix.



a. Design dimensions and pipe layout, including approximate locations of M180 pavement cratering shots

b. View of autobahn during testing with the M2A3 shaped charge. Near end is 8 in. thick

Figure 4. WES test site near North Boundary Road, Observation Tower 10.1, Kofa Range

pipe shot layouts are shown in Figure 5.

18. Emplacement of the two 600-ft pipes required excavation. The first was placed along the center line of 6SR5 (Figure 5), excavated to a 5-ft depth. The pipe was assembled in 40-ft sections which were lowered into the trench and, in turn, assembled into the 600-ft length shown in Figure 6. Breakwires for measurement of detonation velocity (discussed in paragraph 33) were glued to the pipe after it was assembled in the trench. The trench for the second 600-ft pipe, 6SR3, was placed 50 ft west of and parallel to the 1978 6SR3 center line. The extra spacing served to minimize interference by the ejecta from the 100-ft pipe at 6SR4.

19. The detonation velocity of the BA in the 600-ft pipes was to be measured by means of a series of breakwires attached to the pipe at

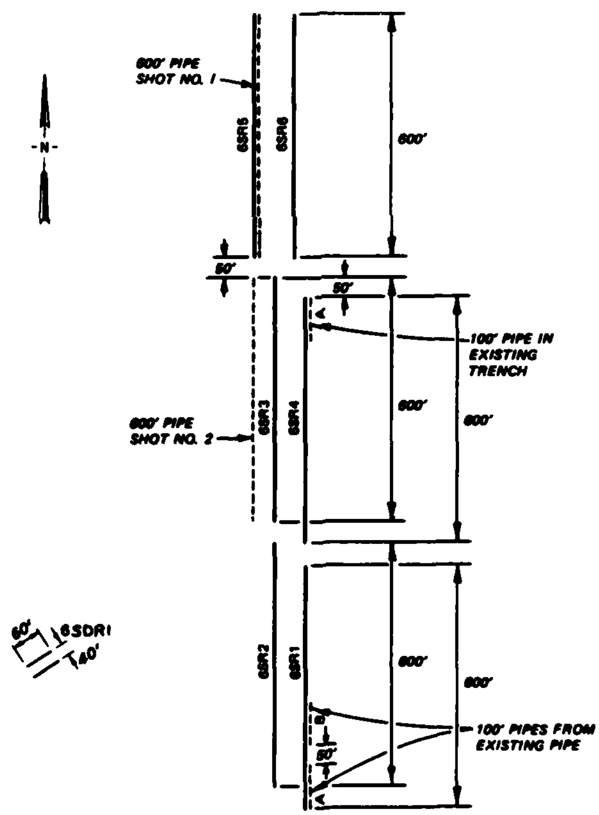
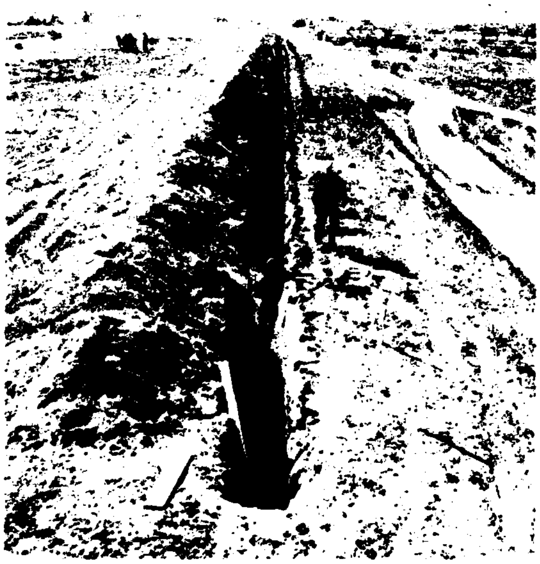


Figure 5. Pipe shot layout at North Cibola site. Solid lines indicate layout for 1978 tests. Dotted lines indicate where pipes were placed for 1980 tests

a. Attaching and testing a breakwire



b. Initial backfilling at breakwire location. Breakwires are attached to stakes at right of trench

Figure 6. Breakwire installation on 600-ft pipe

various measured distances from the booster. (The 600-ft pipes were boostered from only one end.) These wires are designed to break during detonation, registering arrival time for calculation of detonation velocity. At each breakwire location, the pipe was sanded with 320-grit emery cloth, and a No. 33 gage copper wire was glued to the pipe using Devco 5-minute epoxy cement. The wire was soldered to a No. 18 standard insulated copper wire. The breakwire and the joint were taped with duct tape for protection during backfilling. As additional protection, dirt was hand-shoveled over each breakwire location until approximately 6 in. of fill covered the pipe. The free end of the No. 18 wire was tied to a stake next to the trench, awaiting final connection prior to detonation. Figure 6 illustrates breakwire installation. All emplacement trenches at YPG were backfilled to original ground level prior to detonation.

Test Procedure

Slurry boostering

20. The typical* booster employed in the YPG tests conducted by WES consisted of a 1/2- to 1-lb charge of military TNT, connected to a 50-grain detonating cord.** A Reynolds FS-10 firing system with exploding bridgewire (EBW) cap initiated the detonating cord, which initiated the slurry booster, which, in turn, initiated the BA. In this sequence, the booster's function was to deliver a shock wave of sufficient strength to detonate the main explosive (BA).

Pavement breaching (Kofa Range)

21. Of the three pipe arrays emplaced beneath the simulated autobahn in September 1978, two (the 1- and 2-pipe arrays) were fired in October 1979 during WES support to YPG on standardization testing of the BA. Both shots failed, with only the boosters and perhaps a small amount of slurry detonating. Several factors may have contributed to this failure:

---

* Exceptions are noted in the text.
** 50 grains/ft of length.

a. The blasting agent, mixed in a small concrete mixer, was not of the smooth texture that was desired. Tests conducted later by the manufacturer showed that its detonation reliability was marginally critical in the 4-in. pipe.*

b. The TNT booster, approximately the same density as the blasting agent, may have tended to float out of position, and the intimate contact required between booster and slurry may not have existed. C4 has been found to be a better booster (Scheider and Daneker 1980).

22. In January 1980, when full-scale field testing resumed, the remaining triple-pipe array was detonated. At this time, a decision was made to load two of the pipes with slurry and the third with water. This decision was based upon the cratering experience in YPG soil which had been accumulated up to that point, indicating that a 2-pipe array should provide an adequate obstacle in the pavement. The third pipe was filled with water to provide better energy coupling than would have occurred had an empty pipe been present. Details of the triple-pipe emplacement are shown in Figure 7.

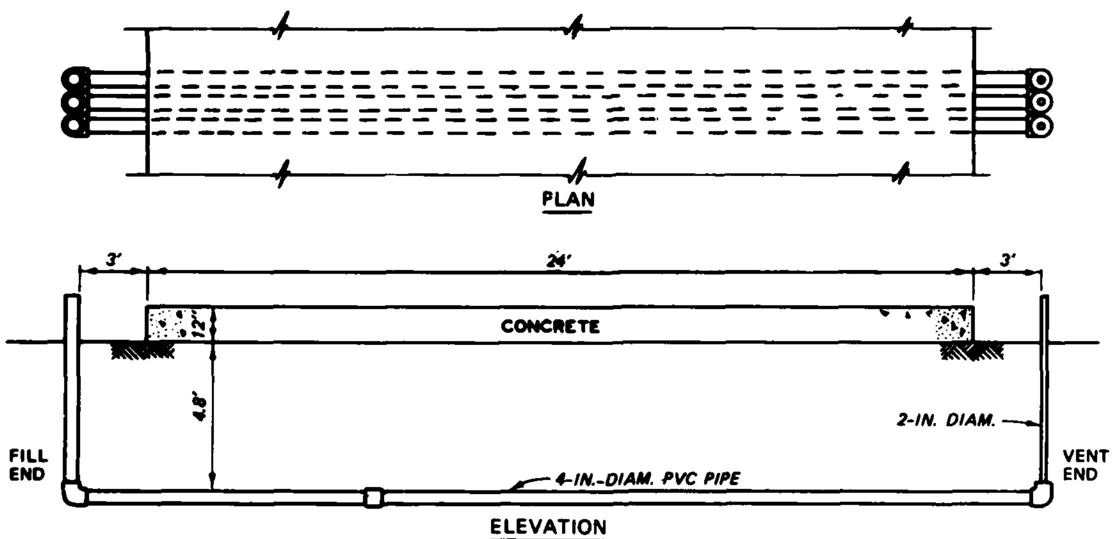


Figure 7. Autobahn triple-pipe array

* A subsequent minor change in formulation appears to have resolved the problem of low sensitivity in 4-in. pipes.

23. The two pipes were hand-filled by pouring the slurry directly from the bags furnished by the manufacturer. Each pipe required approximately 320 lb of BA and took 15 minutes to fill. The 1-lb TNT boosters were primed by wrapping them with 50-grain military detonating cord. Once the pipes were full, the TNT was pushed through the 4-in. standpipe to the elbow in the pipe and held in place by a stick tied to the pipe with tape. Loading and arming were completed within 20 minutes. The detonation was photographed using a Milliken Model DBM-55 high-speed 16-mm movie camera.

Tests with shaped charges

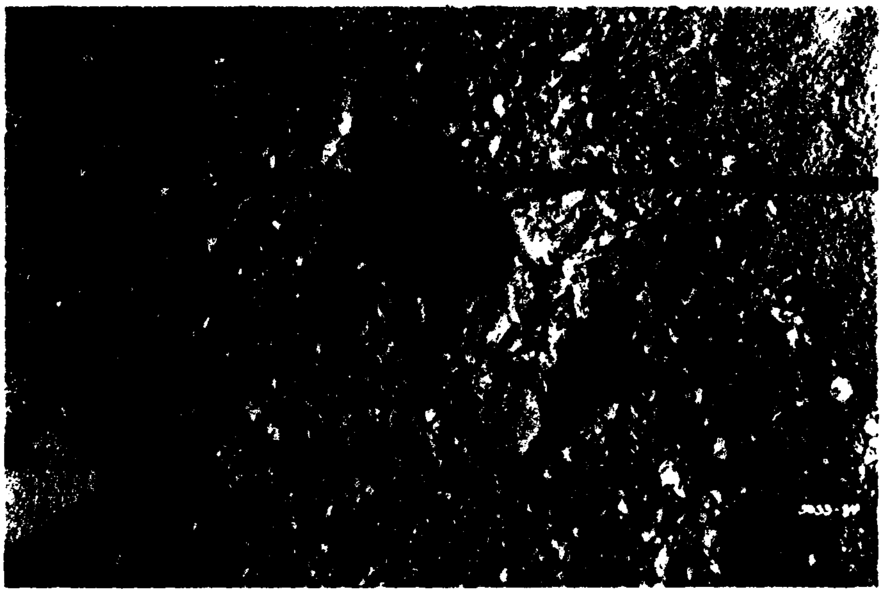
24. One additional test of the slurry was conducted at the pavement site to demonstrate the use of this explosive as an alternative to the Army's standard ammonium nitrate-based cratering charge. The charge hole for the blasting agent was formed by an M2A3 15-lb shaped charge suspended vertically from a tripod 1 ft off the 12-in.-thick pavement. The shaped charge made a hole through the pavement that was hourglass-shaped, with its narrowest dimension being 3 in., much too narrow for the cratering charge. The excavation hole, with a depth of 29 in.,* subsequently served as a charge hole to emplace 90 lb of BA, poured in (Figure 8) to completely fill the cavity.** (By contrast, the standard military cratering charge described in Field Manual 5-25 (Headquarters, Department of the Army 1971) contains 40 lb of explosive packaged in a rigid cylindrical canister with 7-in. diameter.) The relatively small entrance through the concrete helped to partially confine the charge; no additional stemming was provided. The BA charge, bottom-primed with 1 lb of TNT, gave complete detonation (shot 6BA1). A summary description of results is presented in paragraphs 43 and 44.

25. Four M180 shots were conducted on the autobahn. The M180 kit produces its crater in two stages. The shaped charge blows a pilot hole

---

* Measured from approximate midthickness of the concrete pavement.

** A nominal specific gravity of about 1.56 for the BA yields a mass density of 97 to 98 lb/ft^3. Thus, the slurry occupied a total volume, including rubble voids, of approximately 0.93 ft^3, representing an absolute upper limit to the size of the "as found" hole excavated by the M2A3.



a. Hole resulting from 15-lb shaped charge at 1-ft standoff on 11-1/2-in. pavement (shot 6SC7)

b. Pouring slurry into the shaped-charge hole for shot 6BA1. (Disregard bag label, which was for another slurry)

Figure 8. Single-charge cratering experiment on autobahn

in the surface, and the rocket-propelled warhead enters the hole and detonates as a cratering charge. Because the YPG soil was thought to have poor cratering properties, a fifth shot, over soil near the autobahn, was conducted to compare the cratering capability of the M180 with an earlier test series (Carleton, Sullivan, and Rooke 1983) employing the slurry in a single-charge cratering role. The M180 firings were preceded by a six-shot series of M2A3 (15-lb) shaped charges on the two pavement thicknesses to determine empirically an optimum standoff to be used with the M180 over concrete. These results are discussed in paragraph 45. Using the munition design standoff of 4 in., the four autobahn M180 shots were fired, one on the 8-in. section and three on the 12-in. section. Results of all tests are detailed in Part III. Test setups for the M2A3 and M180 shots are shown in Figures 9 and 10, respectively. The M180 kit is described in Appendix B.

<u>North Cibola 100-ft pipe tests</u>

26. The first tests in the 1980 North Cibola series, the 100-ft pipes, involved alternatives to single-point boostering. Possible

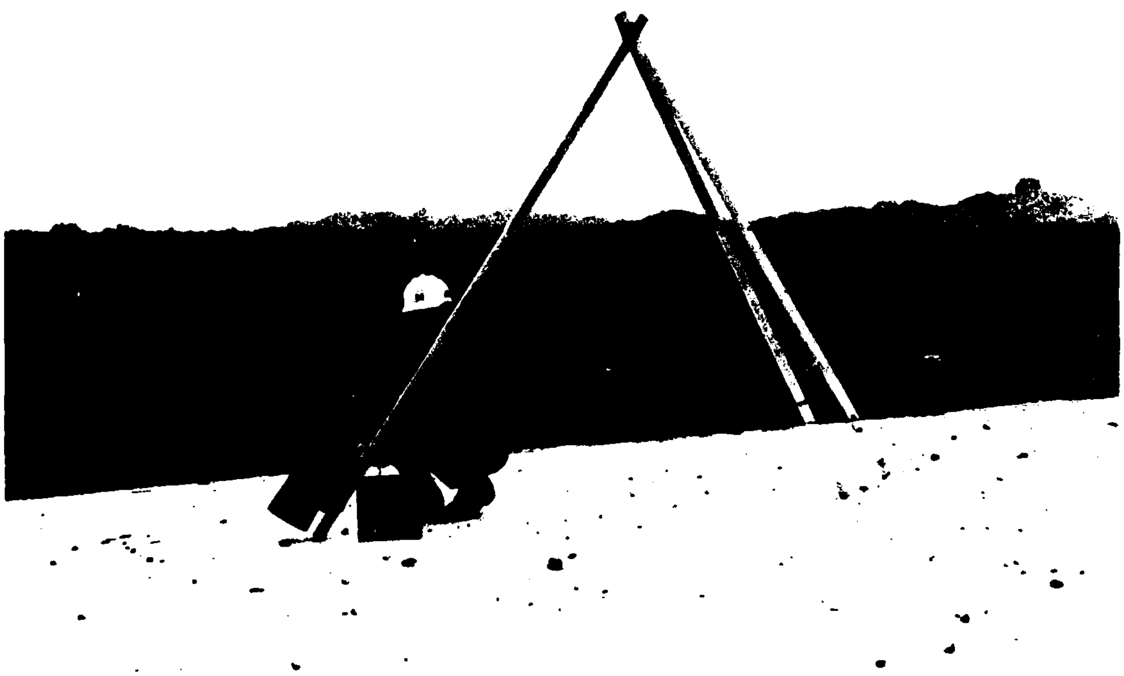
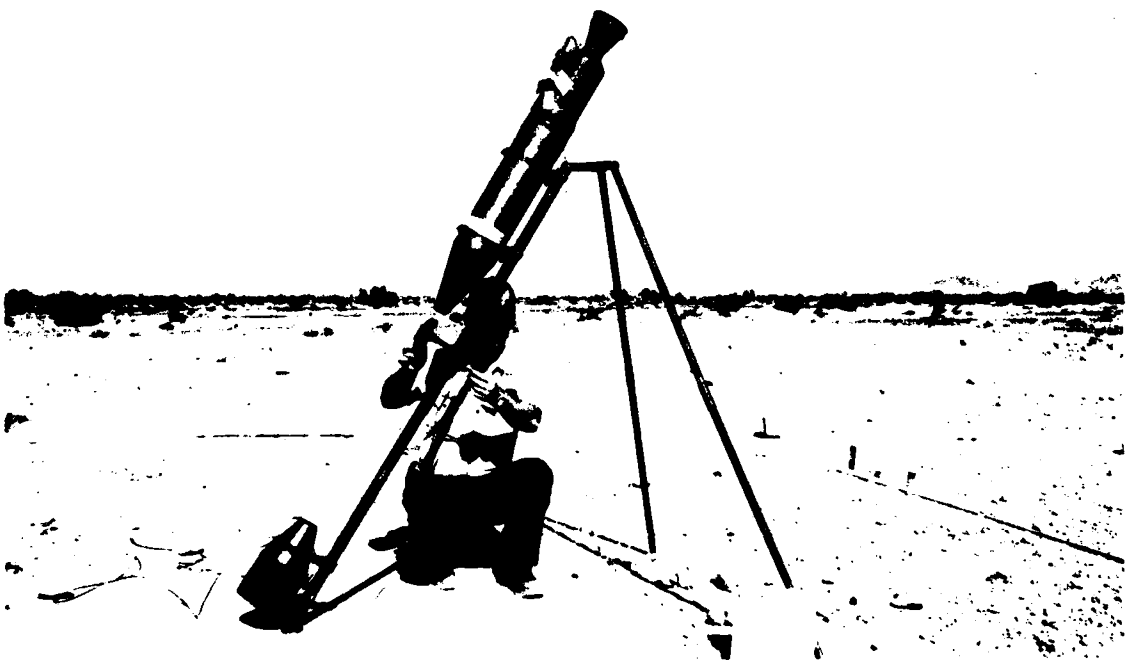


Figure 9. M2A3 shaped-charge assembly positioned for shot 6SC1

a. Attaching rocket motor to the warhead



b. Connecting the firing device for the shaped charge

Figure 10. Preparing the M180 for firing

advantages, particularly in long pipes, include:

a. Redundancy in BA initiation:

(1) Useful in the event of a failure in the initiation sequence.

(2) Possibly essential to a complete detonation in the event of air blockage within the slurry column.

(3) Important in certain military applications, in which reliability can be considered crucial.

b. Ensuring BA detonation along pipe sections of unusual configuration--by employing a primer continuous over a length of the BA charge. The 100-ft length was considered adequate to demonstrate both boostering and ditch uniformity. Because of time and material constraints of the test program, this portion of the test was restricted to the use of detonating cord running the length of the straight 4-in.-diam pipe. The 100-ft pipes (paragraphs 8 and 17) were selected for the study as their relatively short lengths appeared to favor ready comparisons of any effect of primer or booster location on ditch dimension, whereas the 100-ft length of the BA column seemed sufficient for a reasonable assessment of ditch uniformity. By virtue of its ready availability for military use, military detonating cord was selected for this purpose, despite unfavorable commentary in the literature concerning adequacy of detonating cord alone as a "booster" for BA (Cook 1968). It was thought that multiple strands banded together might adequately initiate the slurry.

27. Three boostering techniques were to be tested for comparison to the single-booster technique. The first two of these involved multiple boostering. The original plan called for arming the first 100-ft pipe with a booster charge at each end, the second pipe with a booster at each end and the middle, and the last pipe with a continuous detonating cord strand pulled through the inside of the pipe. However, these plans were changed as testing progressed.

28. All three pipes were configured identically, with an elbow at each end and a vertical standpipe in the middle to provide access for triple boostering (Figure 11). The pipes were pumped using a Moyno J6 air-driven grout pump (see Figure 12) at a pumping pressure of 15 psi or less. The Moyno pump is a positive displacement, encased-auger-type pump, the auger being encased in hard rubber pipe. The hopper slurry

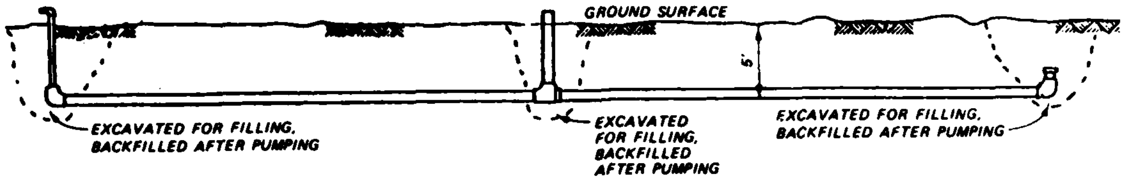


Figure 11. Four-in., 100-ft PVC pipe placement

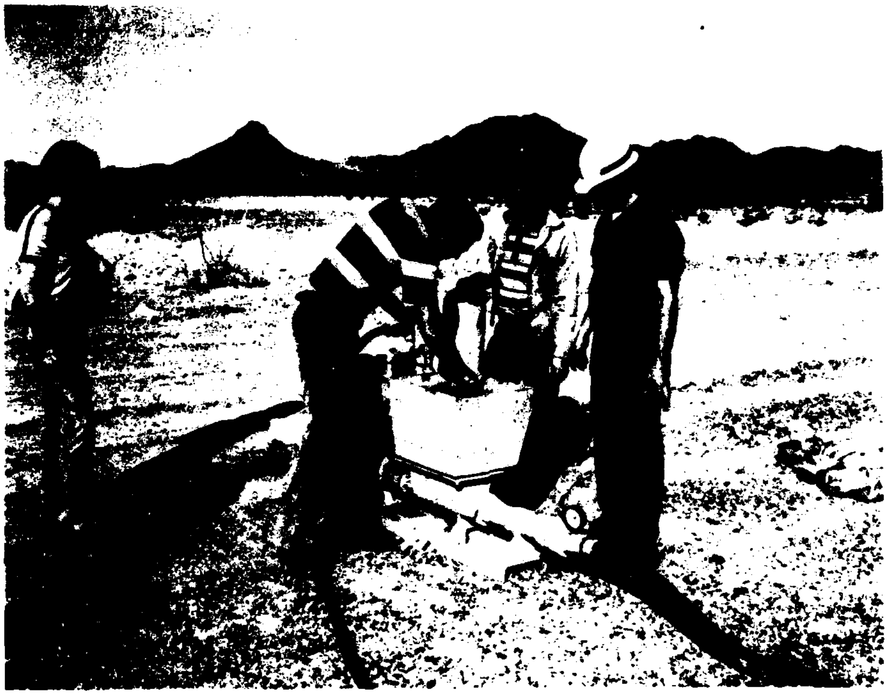


Figure 12. Moyno J6 grout pump. Bagged BA is being poured into hopper

capacity is 230 lb of BA, with a 2-in.-ID outfeed line 25 ft long. A 250-ft^3/min air compressor provided the air pressure for operating the pump. After pumping, the TNT boosters were emplaced and the pipe ends and center standpipe were covered with plastic bags. The vertical feedpipe used for pumping was cut off, the excessive slurry shoveled out of the trench, and the trench backfilled.

29. In the first test event, 6SR1A, the pipe armed with boosters at both ends was detonated. Although no motion-picture coverage is available to confirm this, it appeared to observers that one of the boosters failed. The shape of the resultant ditch (discussed later) seemed to confirm this observation, as it was clearly larger on one

end.* Consequently, it was decided to forego the triple-boostered shot and to repeat the shot geometry of 6SR1A. As in the previous shot, the two boosters were to detonate simultaneously. The Milliken high-speed motion picture camera recorded this second event, 6SR1B, confirming booster detonation at both ends of the pipe.

30. The final 100-ft pipe, 6SR4A, was to have been primed solely with detonating cord. However, separate tests conducted by the BA manufacturer, IRECO, using 50-grain detonating cord had indicated three strands would not reliably detonate the slurry in a 4-in. pipe. Consequently, it was decided to include as part of the test design a preliminary comparison using three 10-ft pipe sections, one with 4 strands, one with 5 strands, and one with a 1/2-lb TNT booster. The detonating cord strands were taped together at approximately 15-in. intervals and pulled through the pipes; the 1/2-lb TNT booster was placed well inside its pipe. The pipes were emplaced in trenches 2 ft deep and were filled by hand-pouring the slurry into them (Figure 13); the trenches were then backfilled. Both the 4-strand and the 5-strand pipes detonated high order. The TNT-boostered BA failed to initiate, although the booster detonated. The backfill covering the end of the pipe was then removed and the exposed pipe found to be intact except for approximately 2 ft blown off one end by the booster. A 1-lb TNT booster was prepared, this time with extra wraps of detonating cord around it. This booster was inserted into the broken end of the pipe far enough to ensure good contact with the remaining slurry. On this second attempt, complete detonation was obtained. Crater inspection showed the two craters initiated by detonating cord to be about the same size; the TNT-initiated crater appeared slightly smaller.

31. The tentative conclusion, that 4 to 5 strands of detonating cord might adequately boost the slurry, was tested in the remaining 100-ft pipe section. The 50-grain cord was again used; 4 strands, equivalent to a standard commercial size, were taped together at

---

* Crater profiles in this report are derived from survey data and profile the apparent crater, as opposed to the underlying true crater. See Appendix C.

Figure 13. Pouring BA into 10-ft pipe. The BA charge was boostered by five strands of detonating cord

intervals as in the preliminary tests and inserted through the feed pipe and into the buried horizontal pipe section. A nylon leader, inserted into the pipe during assembly, was used to pull the detonating cord through; one detonating cord strand was secured to the standpipe to prevent flushing the detonating cord from the pipe during pumping. As in the preliminary tests, the four strands were connected directly to the blasting cap on the ground surface. Upon completion of the pumping operation, the standpipe was cut and removed, and the pipe was detonated. Results of the 100-ft pipe shots are discussed in Part III.

North Cibola 600-ft pipe test

32. As stated in paragraph 7, one of the purposes of the 600-ft pipe shots was to measure BA detonation velocity through a long 4-in.-diam pipe, observing whether or not this velocity is sustained. Detonation velocity of BA is known to depend upon parameters such as charge size and degree of confinement. The relation between detonation velocity and charge diameter for a slurry formulation similar to that

used at YPG is shown in Figure 14; it is obvious that, through the 4-in. pipe size, the BA does not develop its full velocity. This is not necessarily undesirable, since moderate detonation velocities are associated with good earthmoving characteristics. It is important, however, to maintain sufficient detonation velocity to ensure complete,

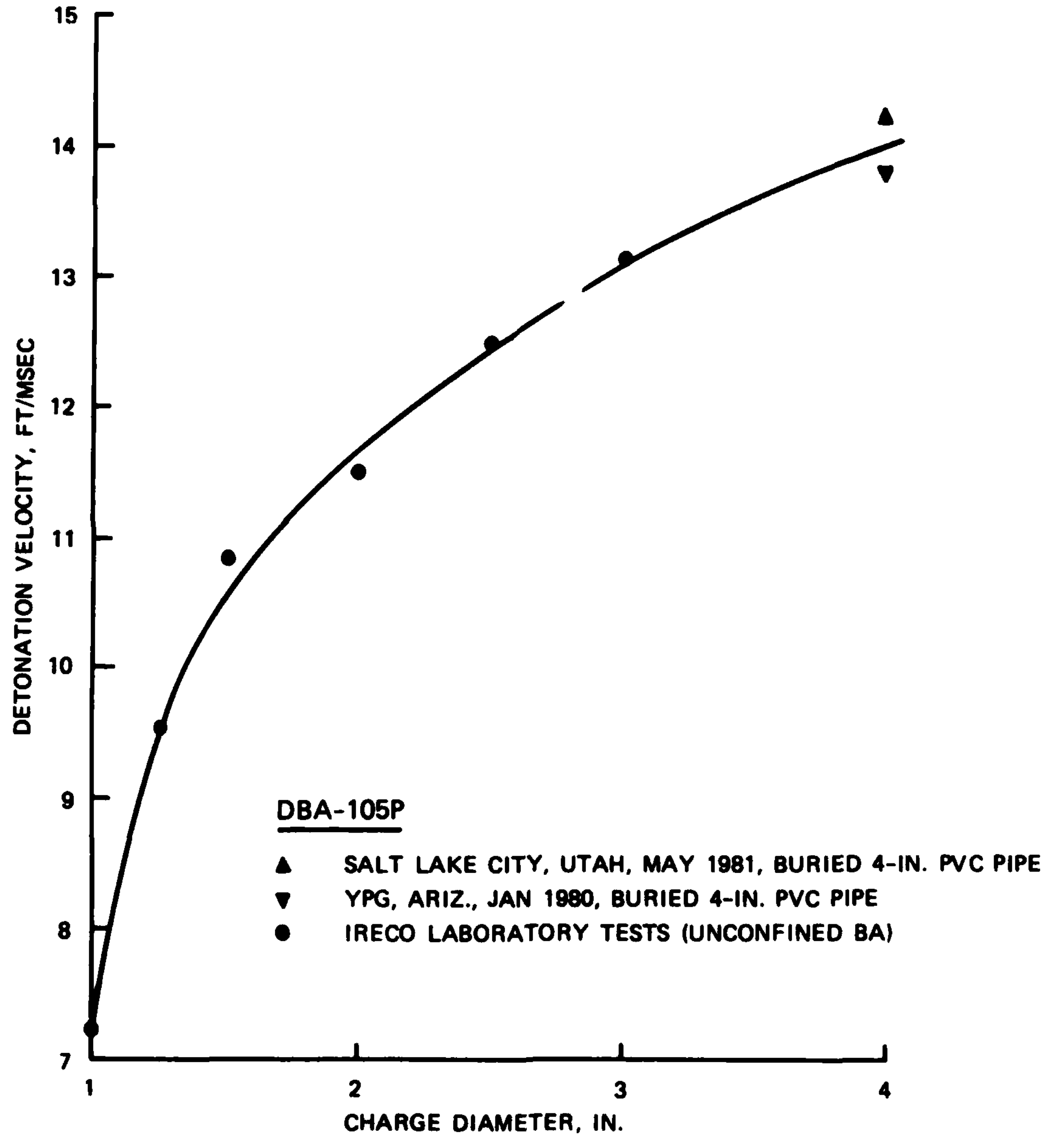


Figure 14. Detonation velocity of DBA-105P as a function of charge diameter

high-order detonation; otherwise, multiple-point boostering might be necessary along the pipe. In order to profile the entire 600-ft length, the pipes were initiated from one end only.

33. Instrumentation. The instrumentation used in these tests was designed to measure arrival time of the detonation front. The breakwires were attached to a battery and resistor so that, when the wire was broken by the detonation, the voltage change across the resistor would be recorded on magnetic tape. When played back at a slower speed, the recorder gives an expanded time resolution. Of a total of 13 channels available, 12 were used for the breakwires and one was tied to the FS-10 firing system.

34. After breakwire installation (described in paragraph 19), both 600-ft pipes were pressure-tested to 100 psi for 5 minutes (Figure 15). The breakwires were connected to the main instrumentation cable by means of Belden 5-strand cable orthogonal to the pipe; the main cable was laid along the ground surface parallel to the pipe and 75 ft

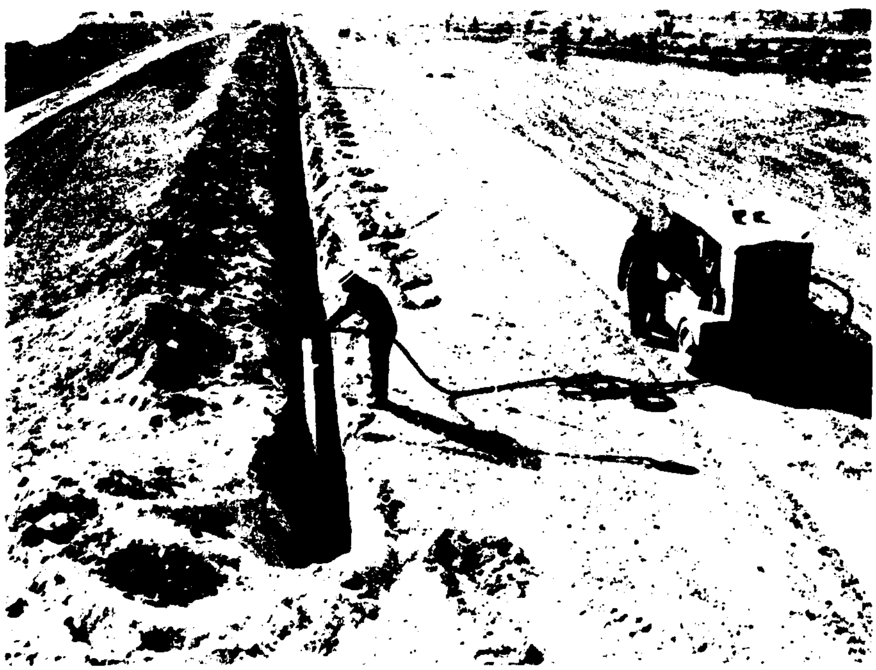


Figure 15. Pressure testing of 600-ft pipe prior to backfilling

to one side. Breakwire continuity was tested following the pressure test, then again after the backfilling operation was complete. Both trenches were backfilled prior to slurry pumping.

35. Slurry pumping. Two different pumping methods were to be tested with the 600-ft pipes. The first pipe (6SR5) was to be pumped from only one end. In filling the second pipe (6SR3), a station pumping technique, in which the pump is moved to a new pumping station at some length along the pipe, was to be tested in anticipation of possible problems connected with the pumping of very long pipes. (If, for some reason, the pumping pressure requirements were to exceed the capacity or safety limits of the pumping system, some method of station pumping would be required.) For this second procedure, a reliable pump of light weight is clearly desirable.

36. Shot 6SR5. The first 600-ft pipe was pumped using the Moyno J-6 grout pump described in paragraph 28. Pumping pressures were gradually increased to maintain a fairly constant flow rate into the pipe. A total of 5600 lb of blasting agent was pumped into the pipe in 42 minutes (including several delays) at a peak pressure of 60 psi. During the first 20 minutes of pumping, a check was made of pumping rate. Two men dumped the bags of slurry into the hopper, and the pumping pressure was raised to keep pace with their rate but did not exceed 50 psi. The men worked at a steady but comfortable rate, loading 400 to 450 lb per minute. These rates were sustained only during three 1-minute test intervals. Pumping was interrupted on several occasions by ejection of slurry from the pump hopper, apparently from the inability of the pump to accept the slurry at the attempted loading rate.

37. Special care was exercised to prevent the introduction of excessive air into the pipes, and for this reason both 600-ft pipes were pumped from the low ends against an elevation differential of 4 to 5 ft, with the expectation that any trapped air could be more easily vented in the upslope direction. Six-ft-high standpipes at the pumping stations (Figure 16) compensated for the head differentials.

38. The BA was boostered with a 1-lb block of TNT wrapped with detonating cord, pushed to a point in the elbow of the bottom of the

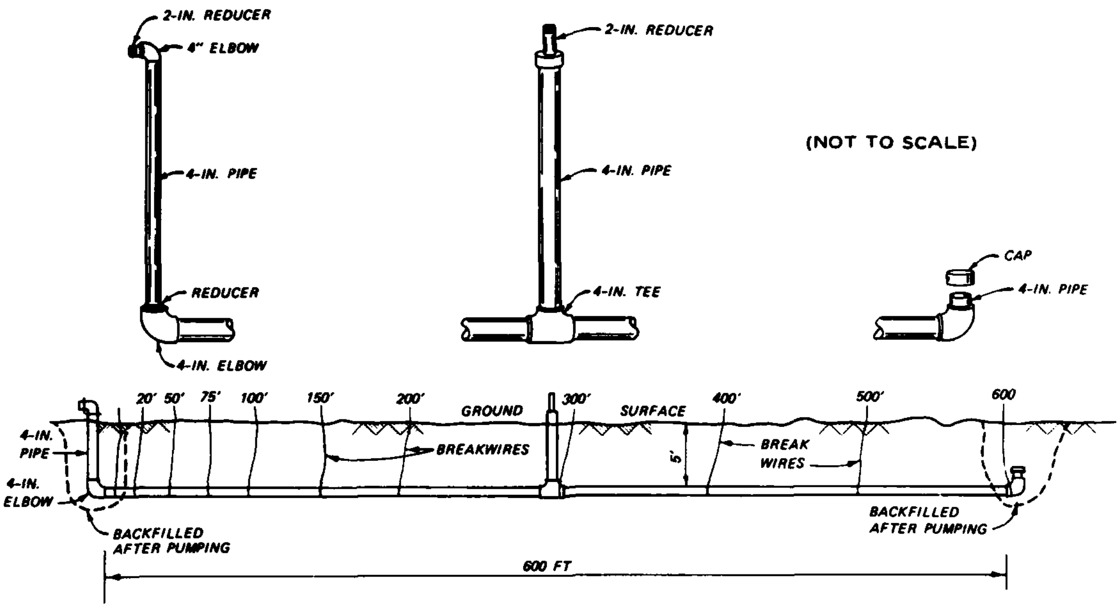


Figure 16. Six-hundred-ft pipe section showing couplings and breakwires

standpipe, immersed in the slurry, and held in place by the push stick tied to the pipe. The detonating cord was attached to an EBW cap, initiated by the FS-10. The first attempt to detonate 6SR5 resulted in a misfire; the booster detonated but failed to initiate the slurry.* As a result of this detonation, the zero-station breakwire was destroyed. The pipe, rearmed from the opposite end with two 1-lb TNT blocks, underwent successful high-order detonation throughout the charge length, as evidenced by the detonation velocity values registered for the shot.

39. Shot 6SR3. The test procedure for the second 600-ft pipe was identical with the first, except for the pumping and arming procedures. This pipe was filled using the station pumping technique and a Wilden model M-8 diaphragm pump furnished by IRECO (see Figure 17). This pump is also air-driven, with output pumping pressure, neglecting

---

* The probable cause of initiation failures described herein, and in paragraphs 29 (a probable failure of one booster) and 30, was low-order detonation of the TNT, which was found to be old.

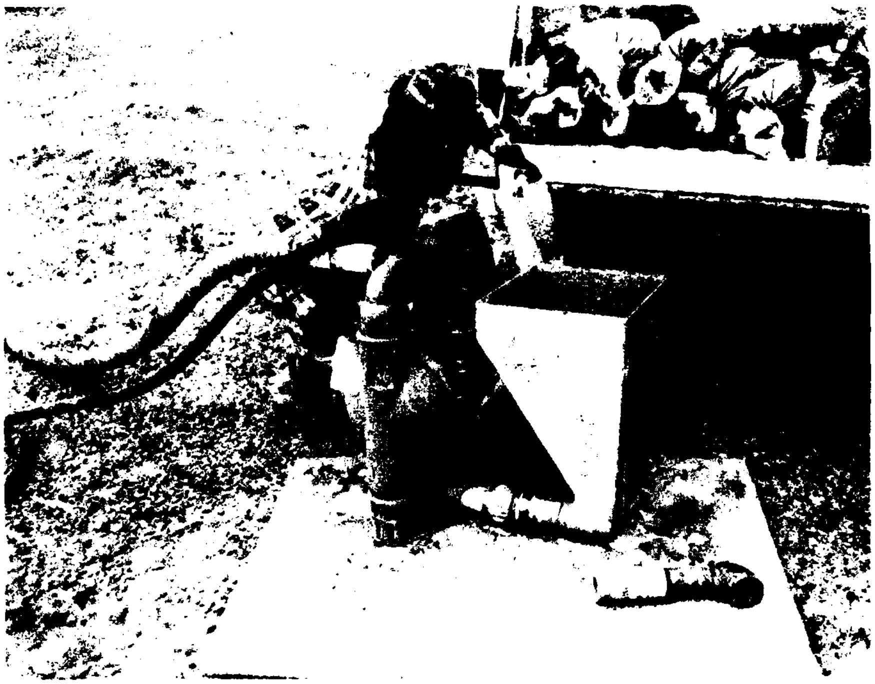


Figure 17. Pumping premixed, bagged slurry with Wilden M-8 diaphragm pump

friction loss, approximately equal to input air pressure. The air compressor was operated at 80 psi.* The center standpipe was vented, with the far end initially sealed. Pumping was continued until the slurry began to vent from the midstation. The pipe was then sealed at the initial pumping station, vented at the far end, and the pump was connected to the midstation standpipe. Pumping from the midstation was continued until slurry began flowing from the far end, which was thereupon sealed. The Wilden was a decided improvement in pumping capability. There was no problem of slurry rejection; overall pumping rate was approximately 180 lb per minute.

* The pump diaphragm operates alternately on two chambers. Thus, a pressure setting of 80 psi implies a rhythmically varying output pressure with peak values of 80 psi, minus losses associated with fluid flow within the pump.

40. The second pipe (6SR3) was armed with a 1-lb block of TNT, placed in the same manner as in the initial attempt with 6SR5. In addition, two 50-lb bags of slurry were armed with 1-lb TNT blocks and placed against the outside of the pipe at the boostered end to ensure initiation. Test results from the two 600-ft pipe shots are given in Part III.

41. Photographic support consisted of two high-speed cameras (a Milliken 500-frame/sec camera, and a Nova 5000-frame/sec camera) and a 35-mm Nikon with a motor drive allowing it to take 35-mm slides at 4 frames/sec. The cameras were located in plywood shelters approximately 1500 ft from the center of the pipe and perpendicular to it. Figure 18 is a photograph of a 600-ft pipe detonation.

Figure 18. Detonation of buried 600-ft pipe at North Cibola. Explosive was DBA-105P

PART III: TEST RESULTS

Pavement Breaching Tests

Shot 6RC3

42. The triple-pipe array (two pipes loaded with BA) containing about 17 lb of slurry per foot of roadway width easily breached the simulated GE autobahn, as shown in Figures 19 and 20. Two cross-sectional surveys* were taken, each positioned 7 ft in from either pavement edge, near the center of a traffic lane. Dimensions of the apparent crater are given in Table 3. The dimension symbols used as column headings are defined in Appendix C. Mobility tests to determine obstacle effectiveness against a tracked vehicle were not scheduled for the Kofa site because of constraints on time and equipment availability. However, the ditch was assessed by personnel of the WES Mobility Systems Division present at the site and judged to present a particularly difficult obstacle to traversal, its effectiveness being due in large part to the raised concrete at the crater edge.

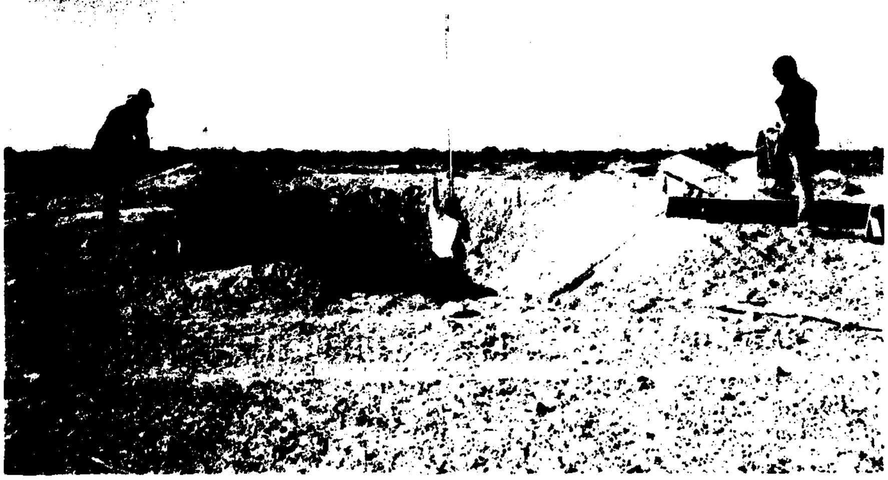
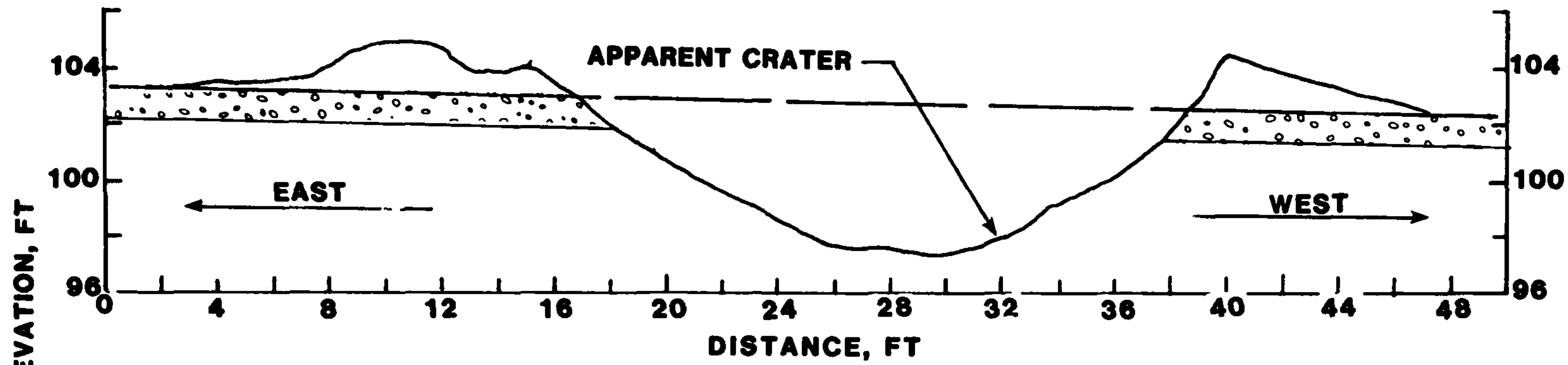
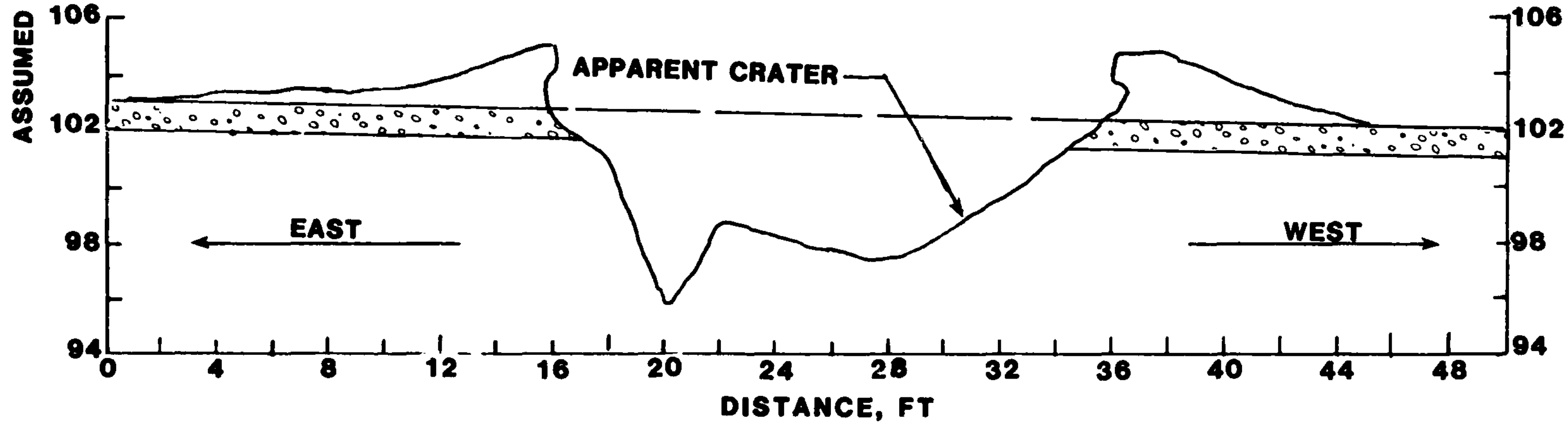


Figure 19. Ditch 6RC3. Cross-sectional view looking along ditch center line

* All crater profiles in this report were derived from survey data, as described in Appendix C.



a. Transverse profile 7 ft from north edge



b. Transverse profile 7 ft from south edge

Figure 20. Cross-sectional (XS) profiles for ditch 6RC3, from double-pipe detonation 5 ft below 12-in. pavement. Roadway runs east-west

Table 3

Ditch Dimensions for Kofa (Autobahn) Shot 6RC3

Survey Location	Apparent Crater Dimensions, ft L_a	W_a	D_a	W_{ob}	D_{ob}	Comment
N-XS		21.1	5.2	28	7.2	
S-XS		19.5	5.1 (7.0)	20	7.4 (9.4)	Parentheses indicate atypical values at sta 20
CL	48		4.7 avg.			Average apparent depth at center line (CL) for ditch section beneath original pavement surface

Shot 6BA1 (shaped charge and slurry--paragraph 24)

43. The crater resulting from the detonation of the 90-lb slurry charge in a shaped-charge borehole is shown in Figure 21. Again, no mobility tests were conducted. While the pavement was breached, the crater appeared to be of minor nuisance value as an obstacle.

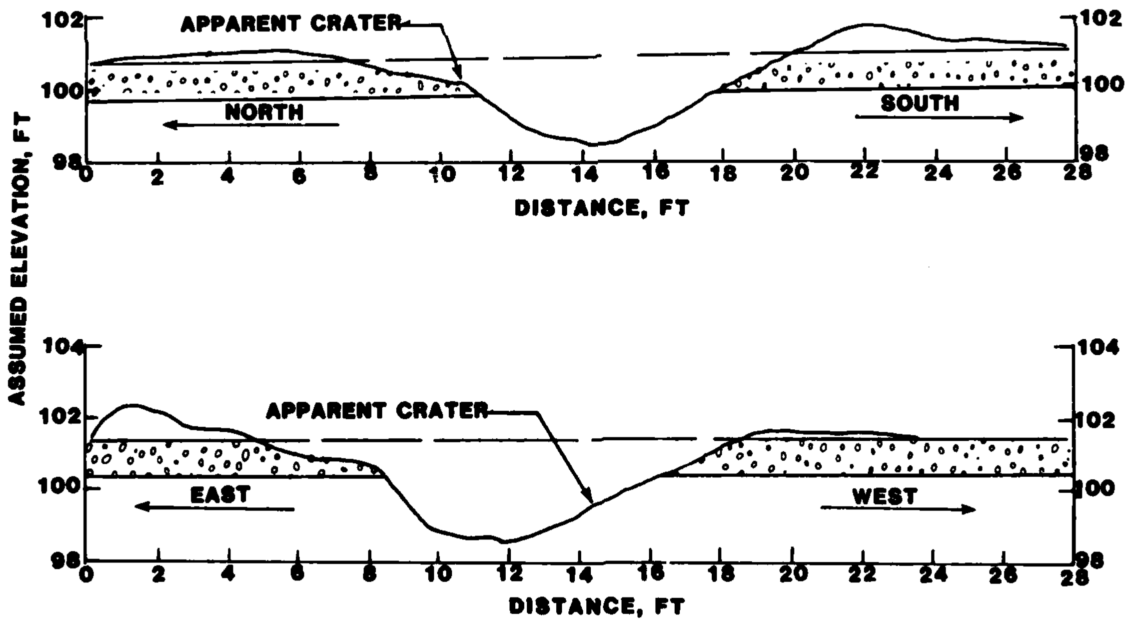
Shots 6SC1-6SC6 (shaped-charge entry holes--paragraph 25)

44. Table 4 presents data describing the entry holes made by the M2A3 shaped charges detonated at varying standoff distances over the pavement. Entry holes are pictured in Figure 22. All shaped charges achieved complete pavement penetration, and some (especially the 12-in. standoff) excavated an irregular path a short distance beneath the pavement. The soil cavity diameters were noticeably larger than the access holes through the concrete. Overall, the advantage of the increased standoff was judged to be marginal and strongly influenced by pavement thickness. Since pavement thickness might not be known in a practical situation, it was decided to accept the 4-in. (design) standoff for tests of the M180.

Shots 6CK1-6CK5 (M180--paragraphs 10 and 25)

45. Table 5 details results of the five M180 shots. Figure 23 illustrates two of the M180 "autobahn" craters, while Figure 24 gives

a. View of crater



b. Crater, EW and NS profiles

Figure 21. Crater 6BA1 from 90-lb BA detonated in the hole excavated by 15-lb shaped charge

Table 4

M2A3 Shaped-Charge Shots

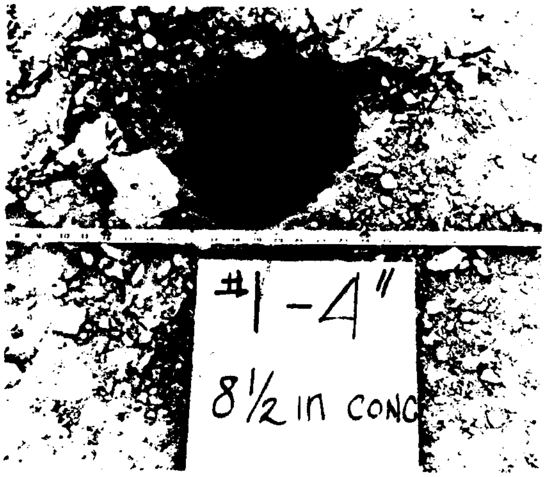
Shot	Nominal Pavement Thickness* in.	Standoff Distance** in.	Pavement Hole Dimensions, in.† Along Trace Axis	Perpendicular To Trace Axis	Remarks
6SC1	8	4	6-3/4	7-1/2	
6SC2	12	6	5	6-1/2	
6SC3	8	6	4-1/2	6-1/2	
6SC4	12	4	6	7	
6SC5	8	12	4	4-1/2	
6SC6	12	12	8	6	
6SC7	12	12	3	3-1/2	Shaped charge vertical to pavement. Cavity was filled with 90 lb BA and detonated (shot 6BA1)

Note: Depths were not measured.

* Actual pavement thickness in the areas tested was about 7-1/2 in. for the nominal 8-in. section, and about 11-1/2 in. for the nominal 12-in. section.

** Measured along line of fire.

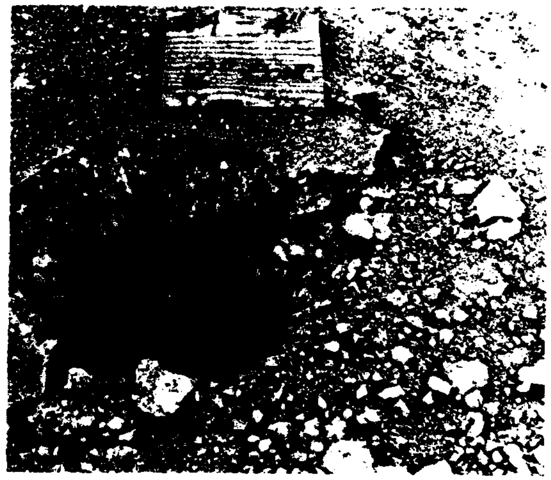
† Measured in plane of pavement. Measurement "along trace axis" refers to hole dimension along the axis formed by the intersection (trace line) of two orthogonal planes: one (a vertical plane) containing the line of missile flight, and the other being the plane of the pavement.



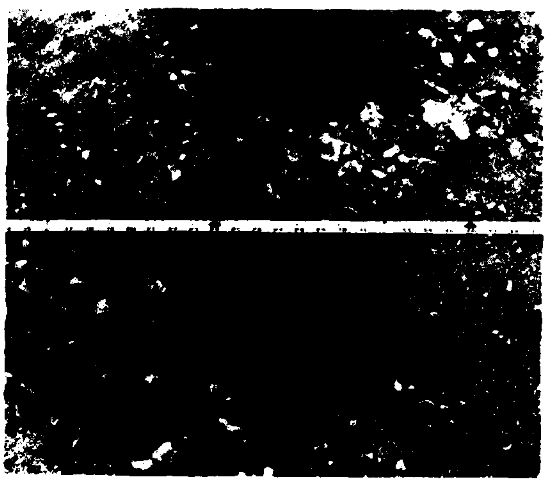
a. Shaped-charge shot 6SC1

b. Shaped-charge shot 6SC2

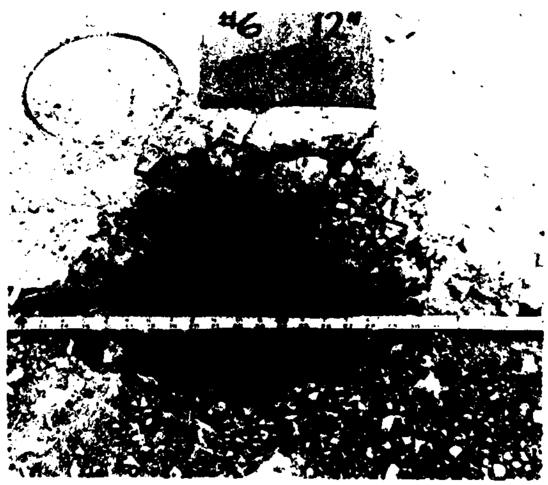
c. Shaped-charge shot 6SC3



d. Shaped-charge shot 6SC4



e. Shaped-charge shot 6SC5



f. Shaped-charge shot 6SC6

Figure 22. Penetration of simulated autobahn by the M2A3 shaped charge

Table 5

M180 Cratering Kit Shots

Shot	Nominal Pavement Thickness* in.	Functioning Sequence: Did Component Fire Normally? Rocket Motor	Shaped Charge	Warhead	Apparent Dimensions of Resulting Crater,** ft Width	Depth	Effective Obstacle?	Remarks
6CK1	8	Yes	Yes	Yes	14.5	3.4	Poor	
6CK2	None	Yes	Yes	Yes	12.0	2.7	Poor	Fired over soil adjacent to autobahn
6CK3	12	Yes	Yes	No	No crater		No	No cratering explosion; warhead explosive burned
6CK4	12	Yes	Yes	Yes	10.7	1.9	No	
6CK5	12	Yes	Yes	No	No crater		No	Warhead lodged in pavement, neither exploded nor burned
6CK5A	12	NA	NA	NA	16.5	2.5	Poor	Warhead detonated by 1-lb TNT

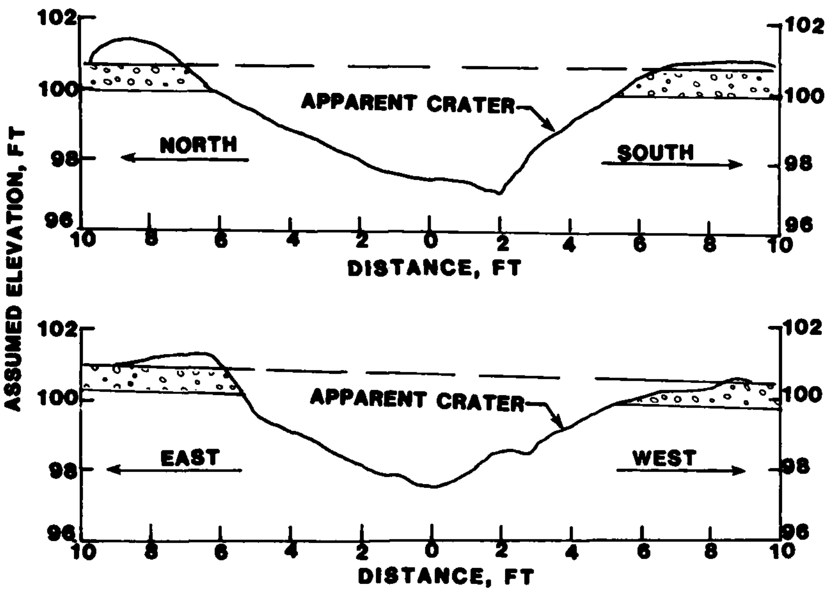
* Actual pavement thicknesses were 7.5 and 11.5 in.

** Relative to preshot pavement surface; 6CK2 dimensions are referenced to original ground.

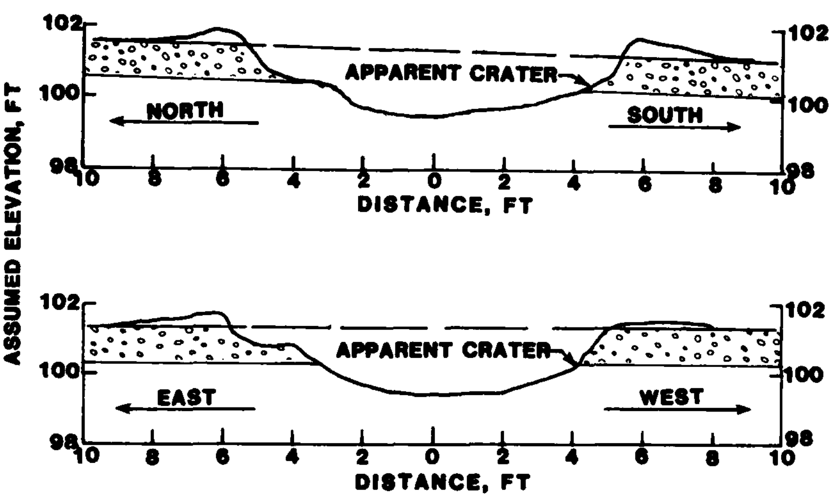
a. M180 crater 6CK1, in 8-in. pavement

b. M180 crater 6CK4, in 12-in. pavement

Figure 23. M180 cratering events

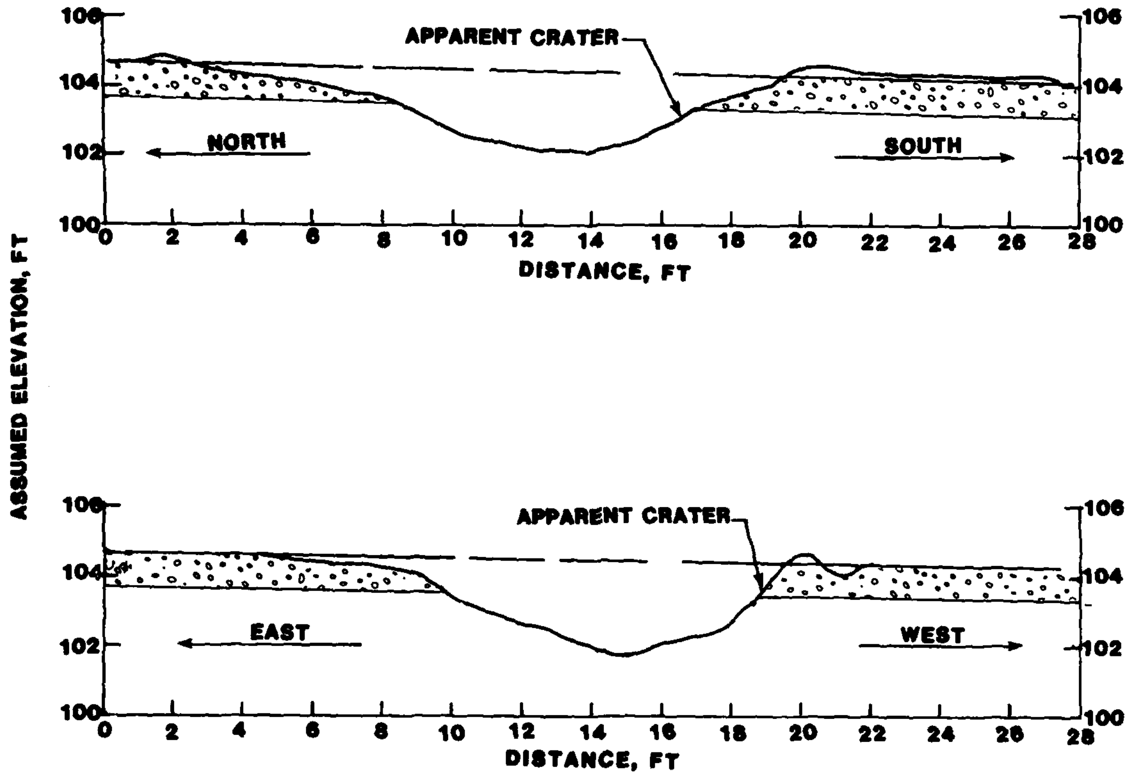


a. 6CK1, EW and NS profiles



b. 6CK4, EW and NS profiles

Figure 24. Crater profiles from M180 pavement shots (Sheet 1 of 2)



c. 6CK5A, NS and EW profiles. Crater resulted from warhead detonation with 1 lb of TNT

Figure 24. (Sheet 2 of 2)

crater profiles. Figure 24 includes shot 6CK5, which was detonated (after malfunctioning) by a 1-lb TNT charge. (Shot 6CK2, fired over soil, is described in paragraph 46.) Note that of the three shots on 12-in. pavement, only one (6CK4) functioned properly, giving a shallow crater. Investigation revealed that the warheads of both 6CK3 and 6CK5 separated* from their rocket motors due to clamp failure or failure of the fiberglass casing just ahead of the clamp (Figure 25). In the case of 6CK5, the motor was found on the surface some distance from the entry hole. Since the warhead detonator is integral to the motor, any separation is likely to cause failure of the warhead to detonate.**

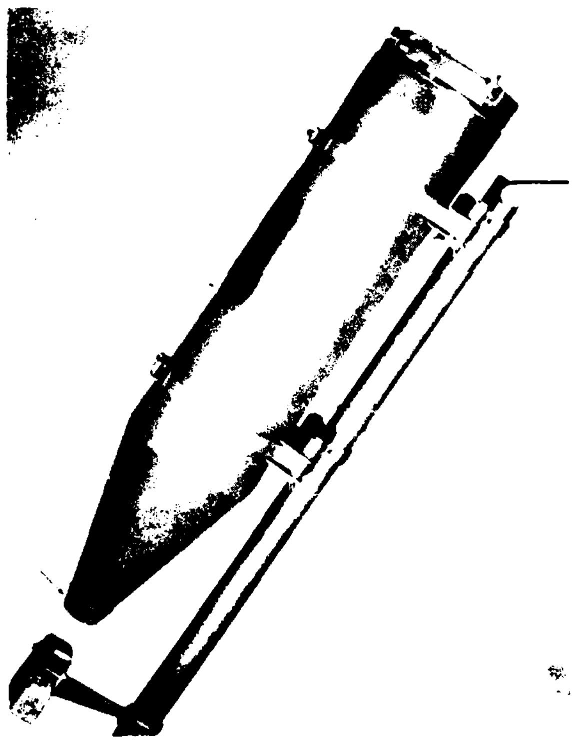


Figure 25. M180 warhead (adapted from Headquarters, Department of the Army 1979)

---

* With 6CK3, a partial separation, as evidenced by a sheared retaining clamp, was likely, accounting for inadequate boostering of the warhead explosive, which burned rather than detonating.

** Mr. Frank Vrabel, ARRADCOM, present at the test.

46. Event 6CK2 over soil is shown in Figure 26. True crater* measurements, obtained on this event only, are included. From these measurements, a weapon burst point was estimated, giving a depth of burst (DOB)** ≈ 4 ft. From previous experience, an apparent crater

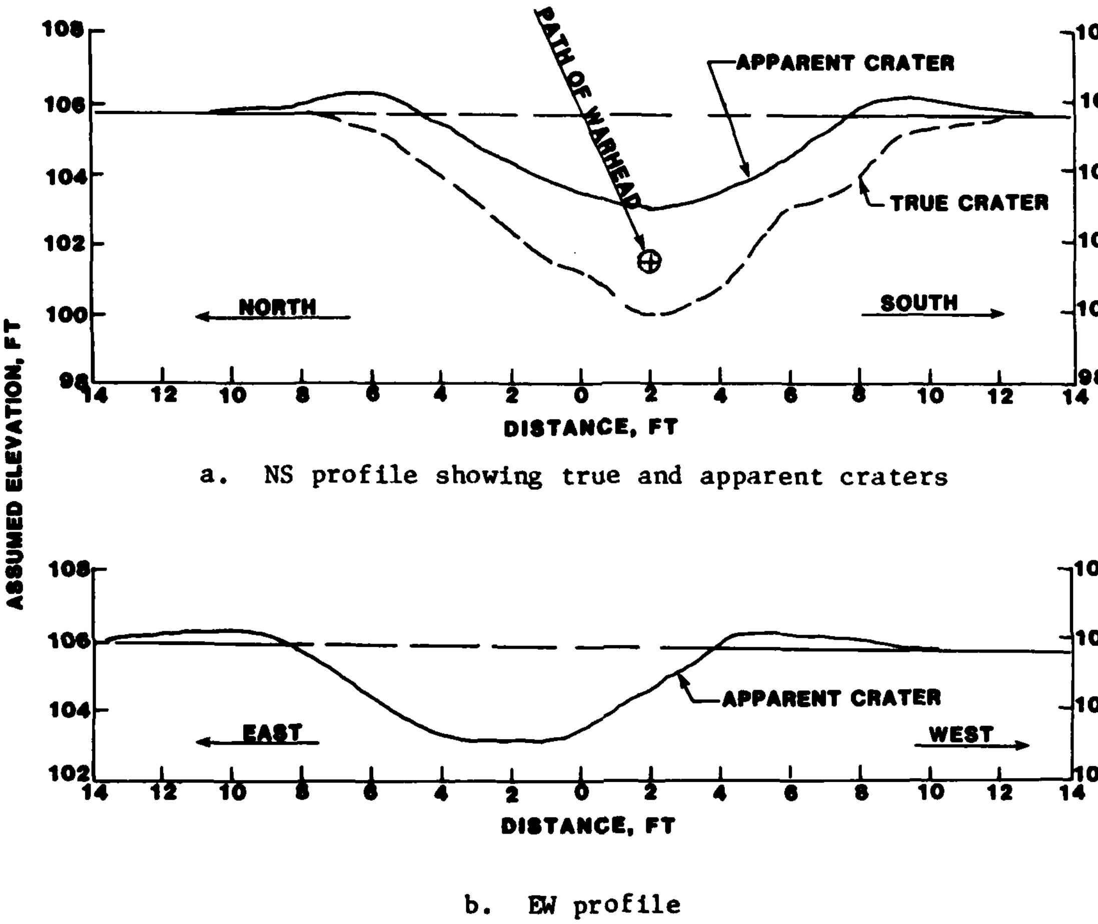


Figure 26. Crater profiles from M180 soil cratering shot 6CK2. Abscissa zero corresponds to point of rocket entry. Detonation point was deduced from true crater

* For an explanation of cratering terms, see Appendix C.

** "DOB" is also used to indicate depth of burial (usually measured to charge center) of an emplaced charge. This usage is followed in Table 6.

radius $r_a \approx 6.3$ ft and an apparent depth $d_a \approx 3.1$ ft would have been expected for this charge size, DOB, and soil type. Considering the differences between the North Cibola and Kofa sites, the uncertainty of the weapon DOB, and the lack of cratering data on the H-6 main explosive charge of the munition, these expected values compare favorably with the observed $r_a = 6.0$ ft and $d_a = 2.7$ ft.

North Cibola Pipe Tests

Shot 6SDR1 (1978 double-row shot)

47. Figures 27 and 28 are a photograph and profiles of the only successful pipe shot in 1978. Basic ditch dimensions for this and other ditch shots are given in Table 6. The shallowness of the ditches and lack of any significant ejecta mound between ditches cast doubt upon

Figure 27. Shot 6SDR1

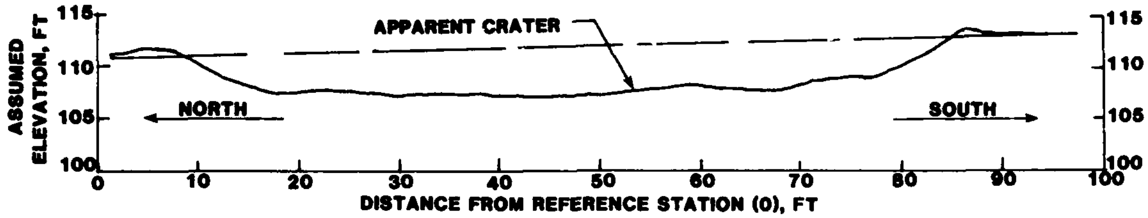
their effectiveness as an armor obstacle. It is not known if this (contaminated?) slurry mix provided a full energy-yield detonation. (The problems associated with the BA used in the 1978 tests are discussed in paragraph 17 and Appendix A.)

Table 6

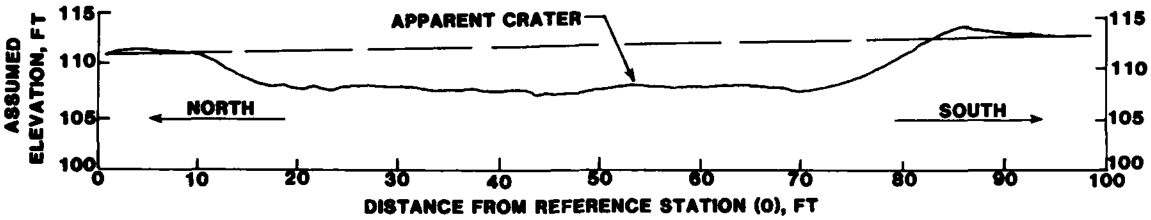
Pipe Placement Data and Representative Ditch Dimensions

Ditch Shot	Shot Date mo/day/year	BA Mix*	Charge Emplacement, ft: Pipe Length	Charge Emplacement, ft: DOB	Apparent Crater, ft: L_a	Apparent Crater, ft: W_a	Apparent Crater, ft: D_a	Apparent Crater, ft: W_{ob}	Apparent Crater, ft: D_{ob}	Comments
				North Cibola Range						
6SDR1										
East Ditch	9/26/78	78, Field	60	4.8 ± 0.2	75	19.2	4.6	23.0	6.0	Double ditch; CL separation = 40 ft. Width and depth are measured at center section of ditch
West Ditch		78, Field	60	4.8 ± 0.2	74	19.5	4.8	23.5	6.5	
6SR1A	1/16/80	80, Factory	100	4.8 ± 0.2	121	18.7	4.6	24	7.2	
6SR1B	1/18/80	80, Factory	100	4.8 ± 0.2	128	20.6	5.2	25	7.1	
6SR4A	1/21/80	80, Factory	100	4.8 ± 0.2	118	14.7	4.4	≈18	5.4	Detonating cord as primer
6SR5	1/21/80	80, Factory	600	4.8 ± 0.2	627	22.1	5.0	26	6.9	
6SR3	1/22/80	80, Factory	600	4.8 ± 0.2	638	22.0	5.1	27	6.9	L_a includes a 10-ft shallow section (depth ≤ 1/2 ft) at south end of ditch
				Kofa Range						
6RC3	1/15/80	80, Factory	30	≈6.0	48	20.3	5.2	24	7.3	Twin BA-filled pipes beneath "autobahn." DOB includes 12 in. of concrete burden over central 24 ft; elsewhere, DOB ≈ 5.0 ft

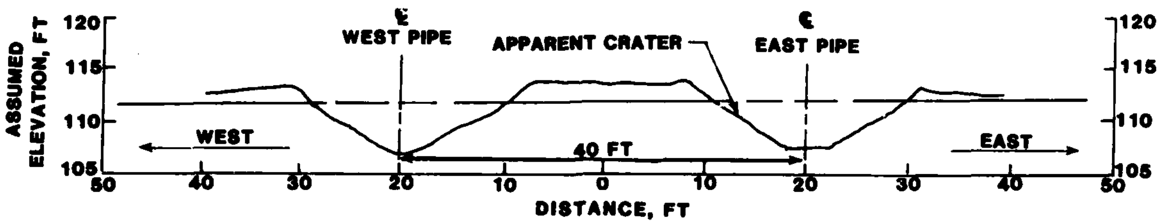
Note: Dimension symbols are defined in Appendix C.
* Linear density of DBA-105P in 4-in.-diam pipe is approximately 8.5 lb/ft.



a. Center line of west pipe



b. Center line of east pipe



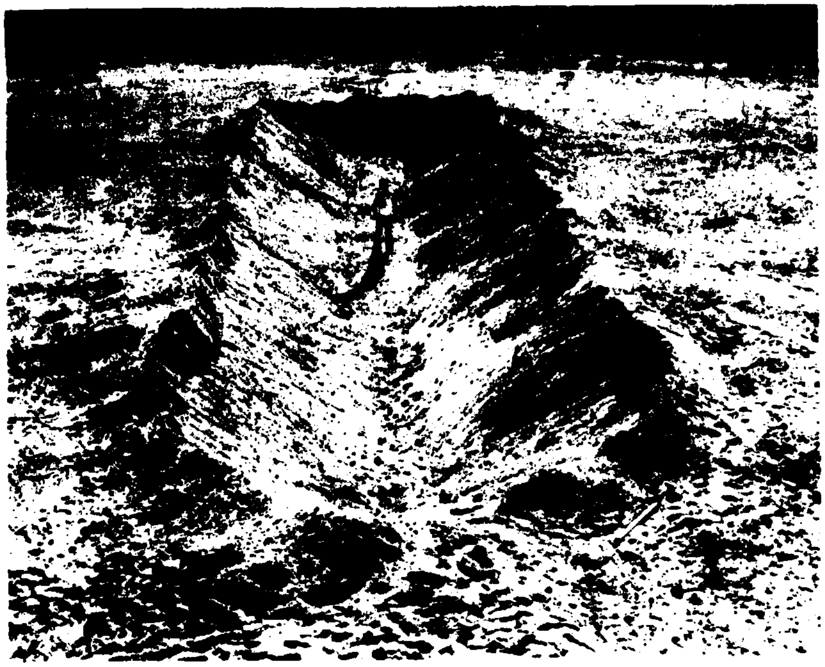
c. Transverse cross section

Figure 28. Double ditch shot 6SDR1, showing center-line and transverse profiles. Transverse profile is at midlength of ditch

Shots 6SR1A, 6SR1B, and
6SR4A (100-ft pipe shots--
paragraphs 8, 17, and 26-31)

48. Photographs and ditch profiles of the 100-ft pipe shots are shown in Figures 29-32. Note that the profiles have been adjusted so that the original ground surfaces are level, thereby facilitating comparisons between profiles. The first shot (6SR1A), in which one booster is suspected of having failed, is clearly larger on one end than the other.*

* A possible explanation for the commonly observed increased crater dimensions at the boostered end is given in Carlson (1961), which, referring to ditch crater shape, describes a "bulb" effect attributed to a decreased pressure in the region behind the detonation front as material is removed. As the detonation proceeds along the linear charge, the newly formed detonation products, working against an unconfined region in one dimension, cannot maintain pressures as high as those which existed instantaneously at the time of initial detonation.



a. Shot 6SR1A

B. Shot 6SR1B. Armored personnel carrier used in mobility tests is in background

Figure 29. Ditches produced by 100-ft BA-filled pipes

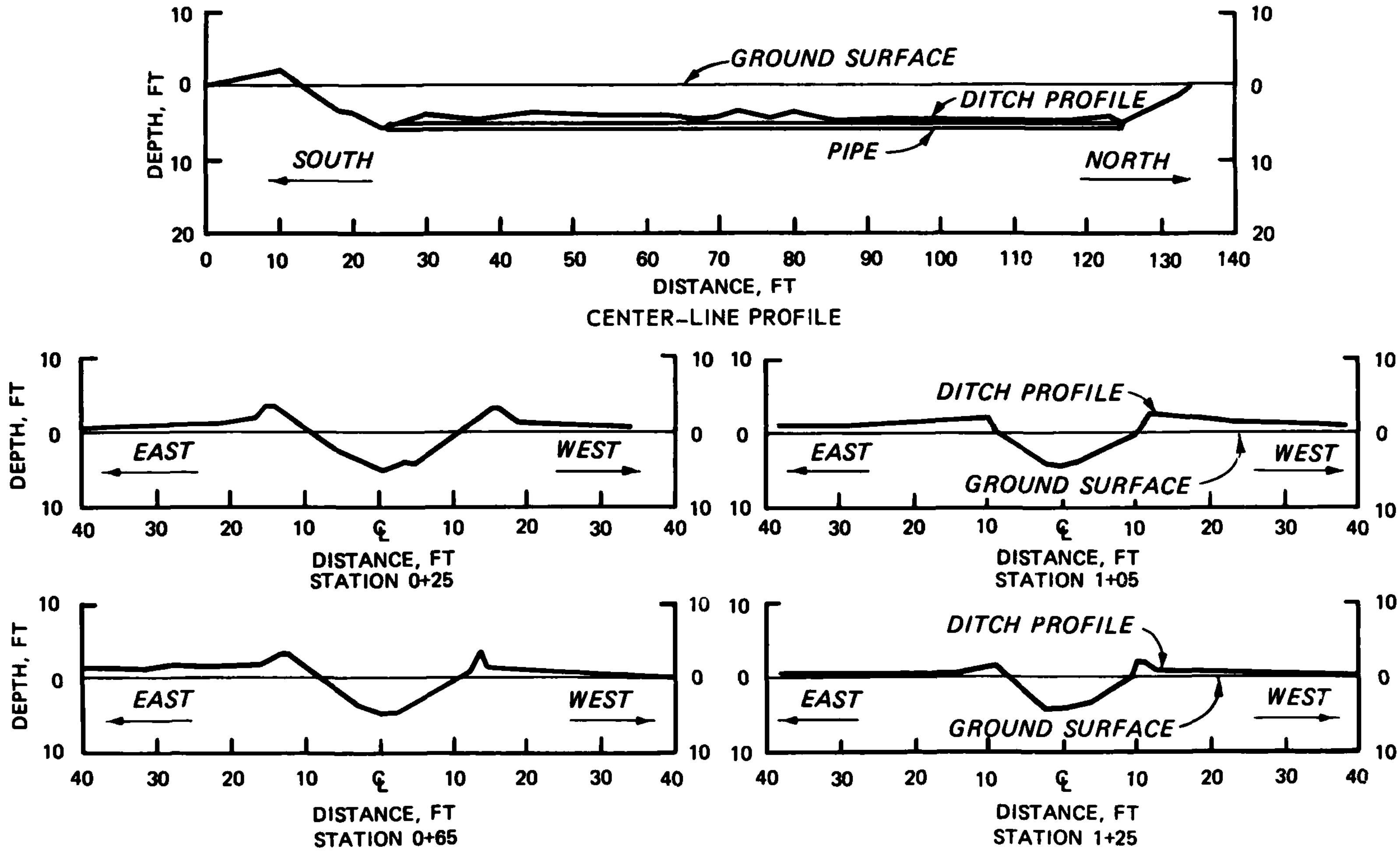


Figure 30. Shot 6SR1A (100-ft pipe shot), longitudinal and transverse profiles

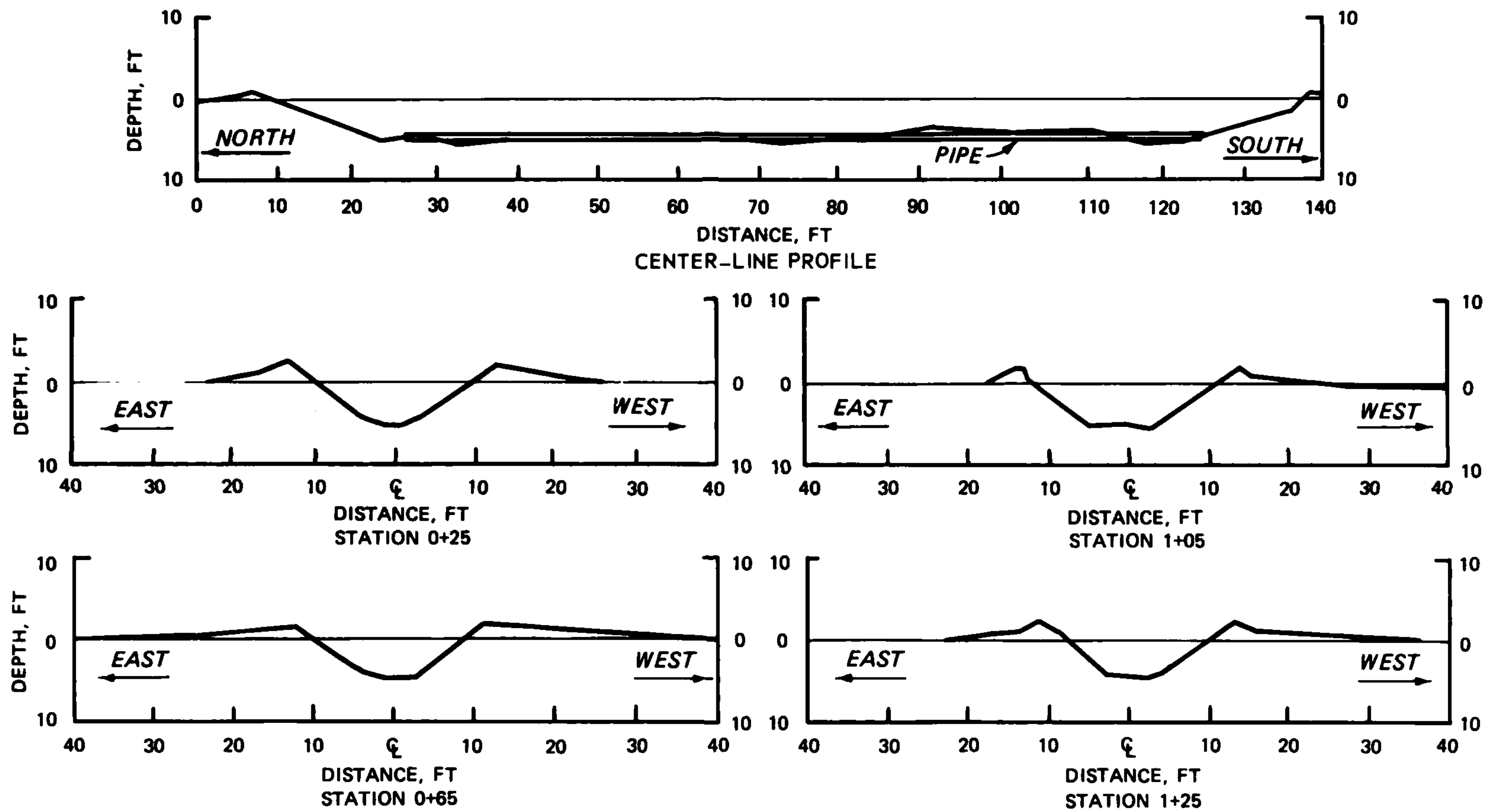


Figure 31. Shot 6SR1B (100-ft pipe shot), longitudinal and transverse profiles

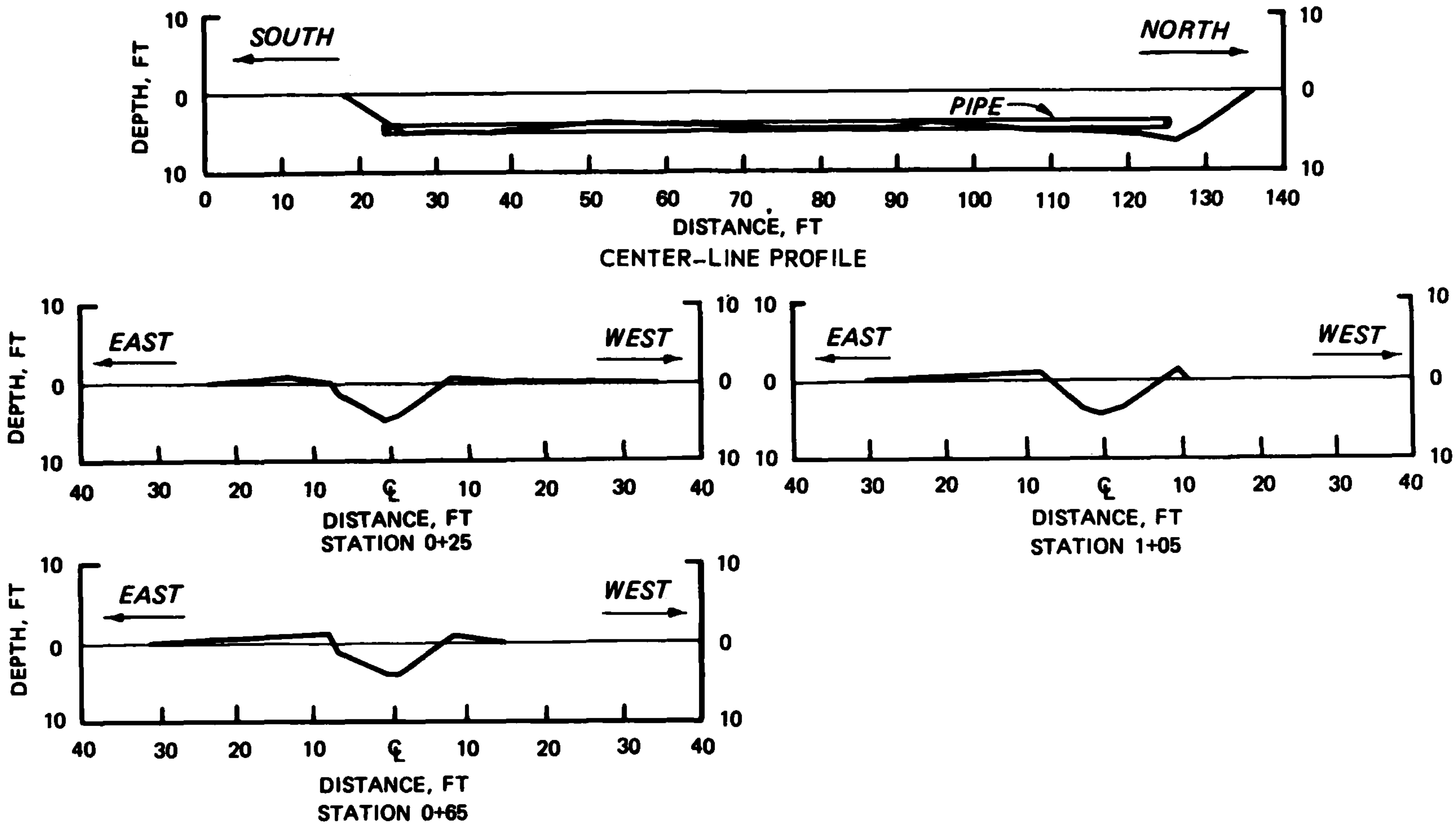


Figure 32. Shot 6SR4A (100-ft pipe primed with detonating cord), longitudinal and transverse profiles

The second 100-ft pipe ditch (6SR1B) was larger in depth and width at both ends, as expected. A third 100-ft pipe shot (6SR4A), testing the feasibility of initiating with detonating cord only, was fired successfully, but the resulting ditch was noticeably smaller than those of the other two 100-ft pipe shots. Apparently four strands of 50-grain detonating cord provide only marginal boostering of the slurry, inadequate for the steady-state values achieved in the 600-ft pipes. Mobility tests are discussed in paragraphs 50 and 51 below.

Shots 6SR5 and 6SR3 (600-ft pipes--paragraphs 7, 18-19, and 32-41)

49. The 600-ft pipes were successfully detonated from one end, resulting in ditches of nearly uniform shape throughout their lengths (Figures 33-35). The detonation velocity measurements showed consistent values for each pipe, with no evidence of degradation (see Figure 36). The implication is that longer pipes can be successfully detonated by boostering at one end only.

50. Time constraints on equipment availability limited mobility testing to the three ditches from the 100-ft pipe shots. Ditches were tested for obstacle value by traversing them with the M113 Armored Personnel Carrier (APC). Each 100-ft ditch was tested at two locations (Figure 37). Ditch 6SR4A, initiated solely with detonating cord, failed to qualify as an effective obstacle. The traversal times and pass attempts for the two successful ditches are as follows:

Ditch	Trial	Time to Cross sec	Number of Pass Attempts Required
6SR1A	1	55	3
	2	75	5
6SR1B	3	50	3
	4	42	3

51. The double-ditch event, 6SDR1, was tested with the APC as part of the aborted 1978 series. Using a minimum of three passage attempts as a criterion for a successful obstacle (Headquarters, Department of the Army 1971), the double ditch failed to qualify. The 40-ft separation between ditch center lines was excessive for the YPG soil,

a. Shot 6SR5

b. Shot 6SR3

Figure 33. Ditches produced by 600-ft BA-filled pipes

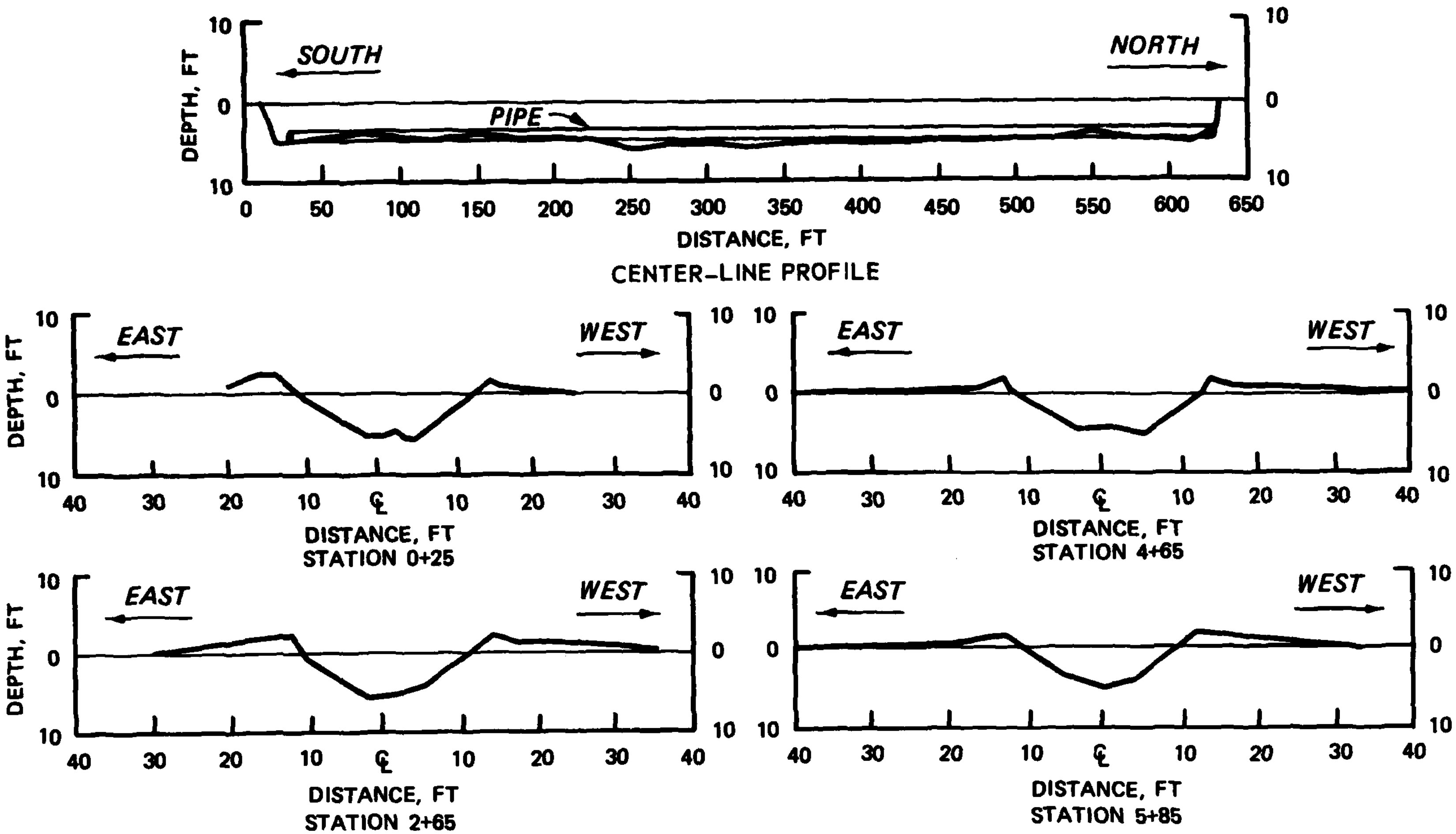


Figure 34. Shot 6SR5 (600-ft pipe shot), longitudinal and transverse profiles. Center-line profile is distorted 5:1 for distance versus depth

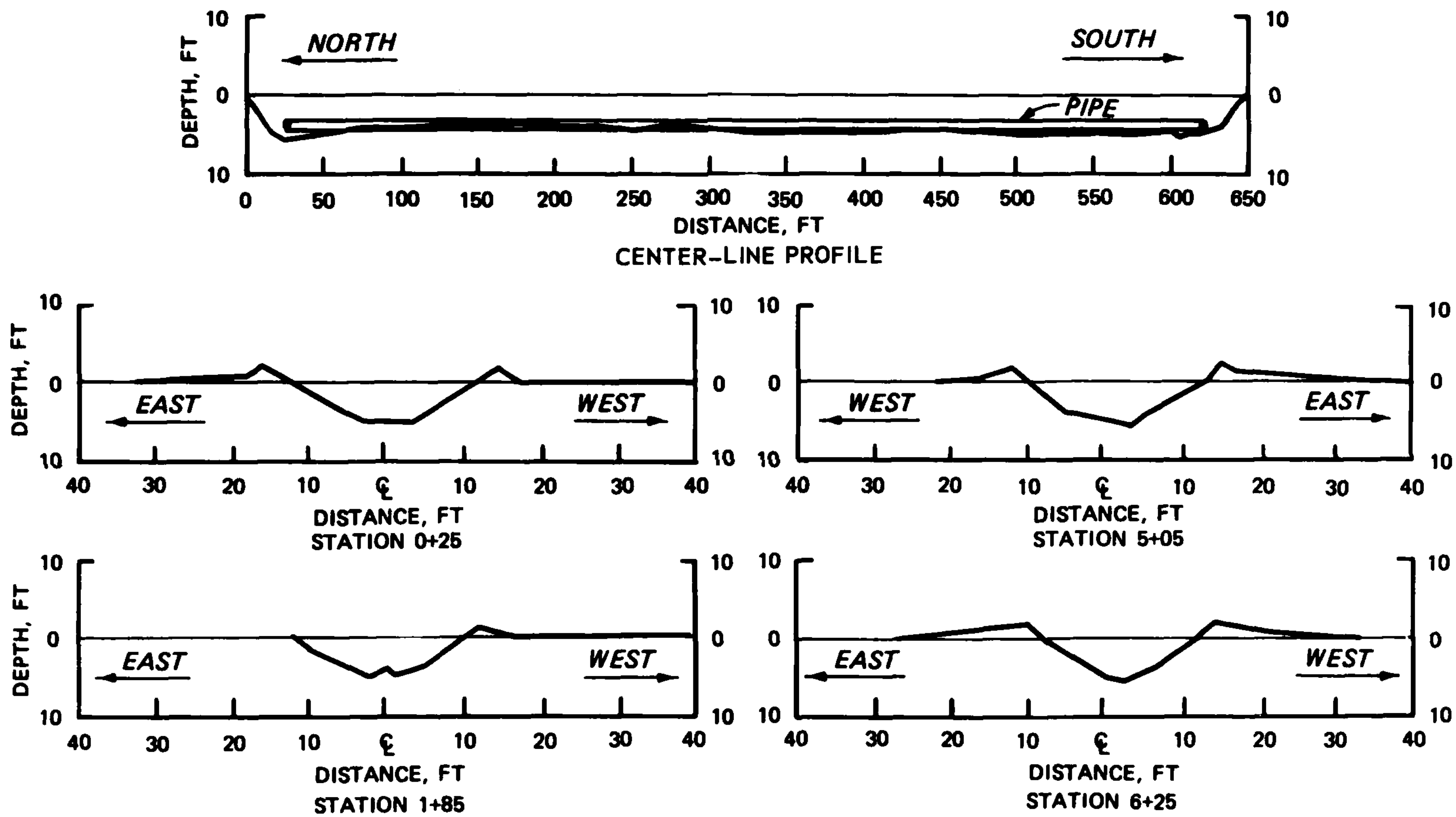
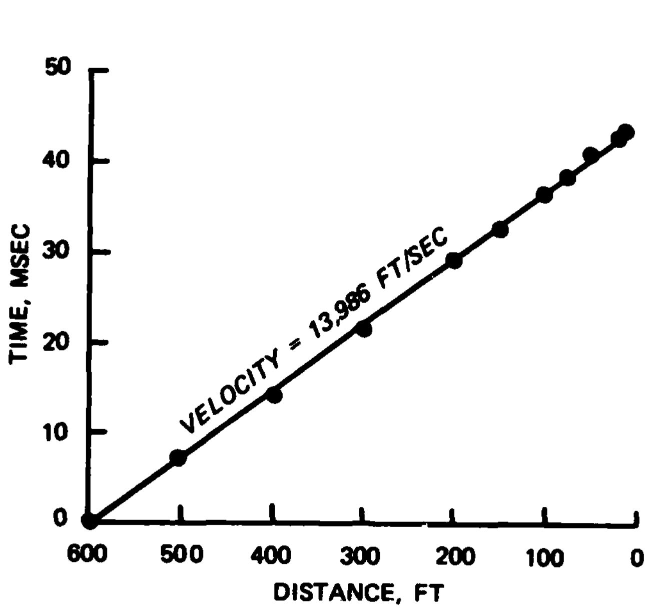
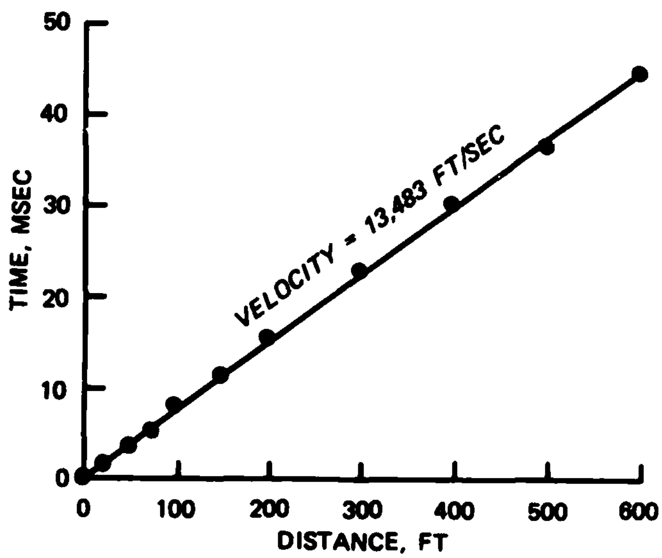


Figure 35. Shot 6SR3 (600-ft pipe shot), longitudinal and transverse profiles. Center-line profile scale is distorted

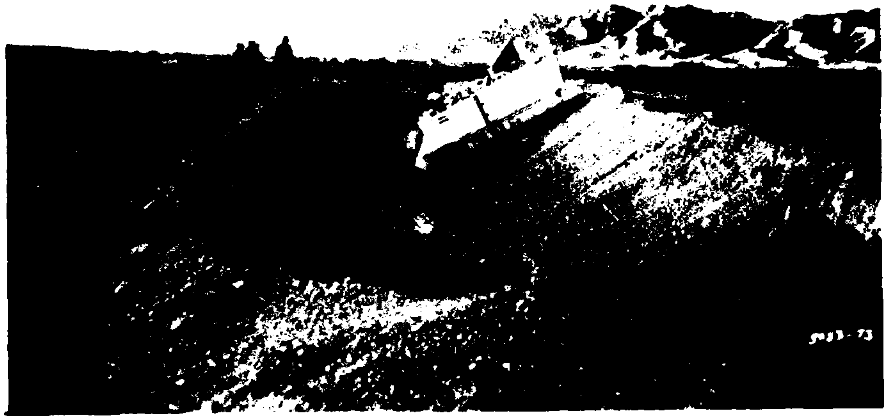


a. Breakwire measurements for shot 6SR5 (initiation at sta 600)



b. Breakwire measurements for shot 6SR3 (initiation at sta 0)

Figure 36. Detonation velocity plots for shots 6SR5 and 6SR3. Abscissa values 0 and 600 locate the ends of the pipes



a. Shot 6SR1A

b. Shot 6SR1B

Figure 37. Mobility testing of 100-ft ditches

which craters poorly, and the center mound, which was supposed to impede passage, did not form.

Discussion

Ditches

52. Inspection of Table 6 values for W_a and D_a shows that the two BA pipes under the simulated autobahn yielded dimensions in general agreement with single pipe under soil, without the additional pavement burden. Although not directly tested for countermobility potential, the autobahn ditch was judged to present a more effective obstacle because of the configuration of the ruptured concrete. From onsite inspection and dimension comparison with the 100-ft ditches, the 600-ft ditches appeared to offer only marginally effective obstacles, whereas the double ditch (1978) failed the three-pass criterion of FM 5-25. This ditch pair, instead of presenting a single obstacle of two ditches with a steep center mound, was in effect two separate ditches, neither of which produced an effective obstacle. In a series of tests conducted by WES to compare cratering in various soils (Carleton, Sullivan, and Rooke 1983), YPG soil at North Cibola demonstrated extremely poor cratering capacity, due in part to extensive caliche layering at the site. Obviously, the deficiencies noted in the YPG ditch shots could be eliminated by improved design; e.g., larger pipes and better spacing.

Road craters

53. The roadway crater for the 90-lb BA charge (paragraph 43) was of minor obstacle value. The shaped-charge hole was too shallow for efficient use of the BA. Optimum DOB, neglecting the concrete overburden, is 5 to 6 ft for 90 lb of DBA-105P in North Cibola soil. The shot could probably have been improved by using a larger shaped charge, such as the 40-lb M3, and/or by "nail-driving" with additional shaped charges fired over the same hole. The liquid BA conforms to hole shape and offers better energy coupling and more effective cratering action than conventional explosives.

Slurry pumping

54. The pumping of the 600-ft pipes presented little problem. As mentioned earlier (paragraph 37), a 4- to 5-ft elevation difference between the two ends of the pipes was easily offset by pumping from the lower end through a 5- to 6-ft standpipe. During pumping of the first pipe, 6SR5, 60 psi was required to pump the final hopper of slurry into the pipe. The second 600-ft pipe, 6SR3, was pumped with a diaphragm pump at a compressor setting of 80 psi, as described in paragraph 39. The diaphragm pump performed better than the grout pump.

55. The station pumping technique presents a potential problem of air entrapment in that pumping from a midstation could conceivably force air backward toward the preceding station. This possibility can be minimized by pumping upslope and venting (uncapping) the nearer upslope standpipes. The successful detonations in the YPG tests indicated that air entrapment did not occur to any significant degree.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

56. The test results demonstrate that buried 600-ft lengths of 4-in. pipe can be successfully pumped full with BA and detonated from one end, producing antiarmor ditches. With no major problem occurring with the 600-ft pipe length, and no degradation of the detonation velocity, the implication is that much longer pipes can be successfully emplaced, pumped, and end-detonated.

57. Station pumping (pumping at different locations along the length of a buried pipe) was successful using the lightweight Wilden M-8 pump. Station pumping appears to offer a workable method of circumventing excessive pressure requirements for exceptionally long pipes or pipes with significant elevation changes.

58. The poor cratering properties of YPG soil reduced the obstacle effectiveness of single antiarmor ditches to marginal acceptability. Larger linear charges are needed. The 40-ft center-line separation was excessive in the double-ditch design.

59. Pavement (simulated autobahn) breaching using BA in previously emplaced pipe should present no problem to achieve an effective roadway crater.

60. Cratering with the M180 was of limited success, with only three successful detonations of the warhead. The craters were small and appeared to offer little or no obstacle value against a tracked vehicle.

Recommendations

61. Additional testing of BA pavement breaching capabilities is needed, incorporating a variety of pavement designs. Test results should ultimately determine the quantities of BA per foot of roadway width for various placement depths, charge confinement conditions, and roadway surfaces.

62. Design modifications of deliberate, hasty, and relieved-face road craters should be considered to properly exploit the BA's advantages over the cratering charge.

63. Further tests of shaped charges on pavements should be conducted to better determine geometries for optimal access hole dimensions for the M180 or whatever demolition technique is desired.

64. Since the 4-in.-diam, BA-filled pipes used in this study produced, at best, marginally effective obstacles, a follow-on series is needed to determine optimal pipe sizes and placement parameters necessary for producing truly effective obstacles in this soil type.

65. Tests should be performed to determine the effect of various pipe configurations, such as 90-degree elbows, constrictions, etc., on propagating the detonation along these configurations. For difficult geometries, alternative boostering procedures should be considered. Results should be useful in evaluating various utility lines as potential containers for the BA in urban obstacle applications.

66. Using the station pumping technique, the maximum feasible length of pipe that can be emplaced, filled, and detonated should be determined. An analysis of pumping pressure requirements for various types, sizes, and lengths of pipe should also be undertaken. Maximum allowable pumping pressures for the BA should be determined.

67. Tests should be considered to isolate any potential problems associated with pumping and detonating long pipes emplaced in uneven ground. Specifically, pipes should be tested to determine how entrapped air affects the detonation process.

68. The antiarmor ditching technique should be further refined to include remote firing, as by the M122 Remote Firing Device.

REFERENCES

Carleton, H. D., Sullivan, J. J., and Rooke, A. D., Jr. 1983. "Cratering and Ditching Experiments with Slurry Blasting Agents; FY 75-FY 78" (in preparation), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Carlson, R. H. 1961. "High Explosive Ditching from Linear Charges," Final Report, Sandia Corporation, Albuquerque, N. Mex.

Cook, M. A. 1968. "Explosives, A Survey of Technical Advances," Industrial and Engineering Chemistry, Vol 60, No. 7.

Headquarters, Department of the Army. 1971. "Explosives and Demolitions," Field Manual 5-25, Washington, D. C.

Headquarters, Department of the Army. 1979. "Demolition Materials," Draft Technical Manual 9-1375-213-12-1, Washington, D. C.

Office, Chief of Engineers, Department of Defense. 1968. "Unified Soil Classification System for Roads, Airfields, Embankments and Foundations," Military Standard MIL-STD-619B, Washington, D. C.

Scheider, M. G., and Daneker, G. W. 1980. "Independent Evaluation Report of DT II for the Demolition Kit, Blasting, XM268," U. S. Army Test and Evaluation Command, Aberdeen Proving Ground, Md.

Woody, C. E., and Coleman, G. K. 1980. "Development Test II (PQT-G) of Demolition Kit, Blasting: XM 268," U. S. Army Tropic Test Center, APO Miami.

APPENDIX A: DEMOLITION KIT, BLASTING, XM268

Background

1. In 1977 the Project Manager, Selected Ammunition, U. S. Army Armament Research and Development Command (ARRADCOM), awarded a contract to IRECO Chemicals, Inc., for development of a blasting agent that would meet Army operational and logistical requirements. In August 1978 the IRECO product DBA-105P, developed to meet these requirements, officially became Demolition Kit, Blasting, XM268.

Description

2. Blasting agent (BA) XM268 is a composition of two materials, one of which has a Department of Transportation Classification of inert and the other a classification of an oxidizer (nonexplosive), but which when mixed, form a highly effective explosive material. The formula of the development test material includes two ingredients: a liquid, and a dry powder. The XM268 kit materials are packaged in a ratio of one plastic container of dry material to two plastic containers of liquid for a total mixed explosive weight of 100 lb. To facilitate handling, 30 of these containers (10 with dry ingredients and 20 with liquid ingredients), having a net weight of 1000 lb of material, are packaged in a wire-bound plywood box mounted on a pallet. Included in each box are 20 bags with ties. The mixed materials can be stored in the bags as explosive Class V materials.

Further Development

3. The composition of DBA-105P, a perchlorate-based aluminized slurry, underwent several changes during the period August 1977-September 1978, but the effects on reported cratering results are not thought to have been significant. Premature reaction of slurry batches in the September 1978 Yuma test led to cancellation of the remainder of that

test. Problems encountered involved self-heating of the mixed blasting agent and gassing of the solid component premix; observations under field conditions are detailed elsewhere.* These problems were subsequently studied by ARRADCOM** and IRECO, and the current stable formulation was implemented. The current formulation has been extensively tested at Fort Rucker and Fort Hood, in Hohenfels, Germany, and in Korea with excellent results.

4. The problems encountered in the 1978 Yuma test (premature exothermic reactions) were triggered by the inadvertent contamination of the aluminum powder with a small amount of magnesium at the aluminum manufacturer's plant. Magnesium is very susceptible to reaction with water and, when mixed with the liquid component (an aqueous solution), initiates a reaction causing the pH of the mix to become extremely basic, thus setting up conditions favorable to an exothermic aluminum-water reaction evolving hydrogen.

5. The new formulation has been well stabilized. Tests have confirmed its improved resistance to premature exothermic reaction. Tests have also verified the long-term stability and the low-temperature capability of the sodium perchlorate solution.

6. The gassing problem in the solid premix has been attributed to the small amount of water in the gum (thickening agent) causing a minute aluminum-water reaction. In the new formulation, the gum has been incorporated into the liquid component. The aluminum coating has been changed from stearic to isostearic acid, a liquid which serves as a hydrophobic coating and as an antidusting agent. These changes contribute to stability under long-term storage and improve mixing and thickening properties, holding them nearly constant over a wide range of temperature conditions.

---

* U. S. Army Engineer Waterways Experiment Station letter report, "Summary Report: Problems Encountered with DBA-105P at Yuma, AZ, 18-29 September 1978," Feb 1979, Vicksburg, Miss.

** Test Integration Working Group (TIWIG), minutes of the 12 September 1978 and 6 February 1979 Meetings, Headquarters, TECOM, Aberdeen Proving Ground, Md.

APPENDIX B: DESCRIPTION OF THE M180 KIT

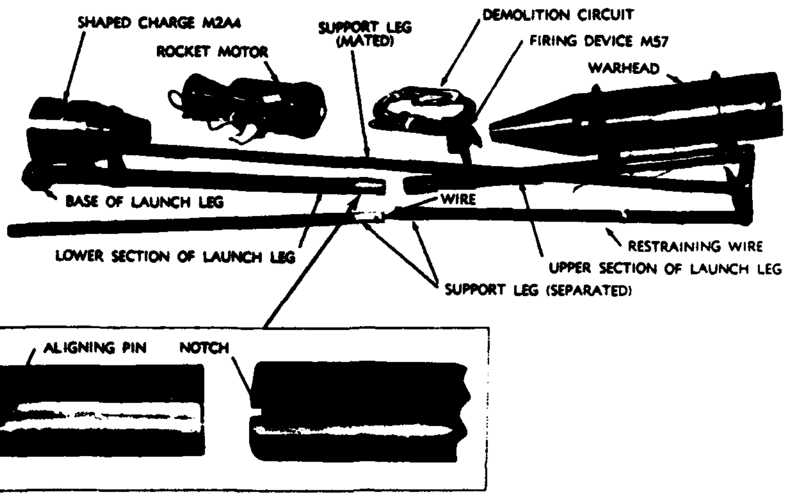
M180 System

1. The M180 Cratering Demolition Kit consists of an M2A4 15-lb shaped charge, an M57 firing device which has been modified, a 40-lb warhead, a rocket motor, a tripod, and a demolition circuit (see Figure B1). The shaped charge, firing device, and warhead are permanently attached to the launch leg of the tripod. The rocket motor, which has the booster for the warhead as an integral part of the demolition circuit, is shipped unattached and is connected when the kit is assembled for use.

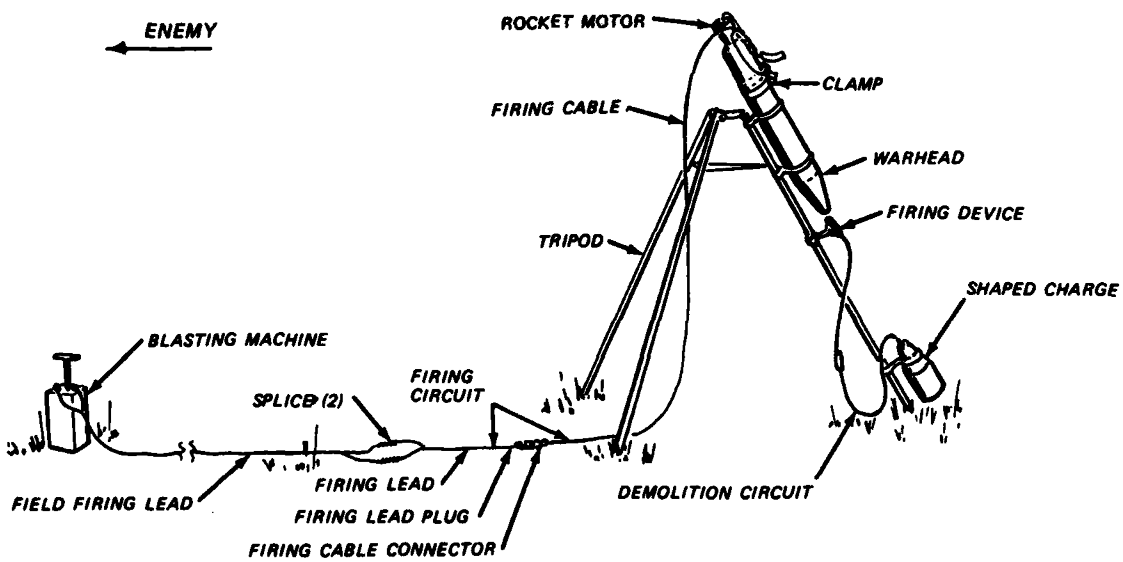
2. A 50-cap blasting machine is used to fire the kit. Current generated by the machine simultaneously ignites the M2 squibs and the delay-time electric blasting cap in the booster. The squibs ignite the propellant grain. The rocket motor builds thrust until the shear strength of the attaching hardware is exceeded. When this occurs the entire assembly, rocket motor and warhead, moves forward, impacting on the M57 firing device. The firing device handle is crushed, generating an electric current in the firing circuit which initiates the shaped charge. The shaped charge blasts a pilot hole into which the warhead is propelled by the rocket. Finally, the delay electric cap in the booster initiates the warhead. The M180 kits were assembled in accordance with Draft Technical Manual 9-1375-213-12-1 (Headquarters, Department of the Army 1979) provided with each kit.

Shaped Charge

3. The shaped charge on the kit is attached to the tripod leg to give a 4-in. standoff as measured along the line of flight from the center base of the shaped charge cone. Because shaped charges are known to penetrate pavements more effectively at greater standoffs, the U. S. Army Engineer Waterways Experiment Station was requested to conduct some preliminary tests of the shaped charge alone at standoffs of 4, 6, and



a. M180 Cratering Demolition Kit



b. Single kit set up for operation

Figure B1. M180 Cratering Demolition Kit composition and employment (Headquarters, Department of the Army 1979)

12 in. against the two different pavement thicknesses, 8 and 12 in.

4. For these tests, six M2A3 15-lb shaped charges were provided by Yuma Proving Ground. The M2A3 differs from the M2A4 only in the booster material located around the capwell. The change was made to decrease the shaped charge's vulnerability to small arms fire, and there is no evidence to indicate any difference in performance of the shaped charges.

5. For the tests described in paragraph 25 of the main text, tripods were constructed using 2- by 2-in. lumber, and the M2A3 shaped charge was taped to one leg using fiber-reinforced duct tape. The legs were tied together with nylon cord to adjust their angle to match that of the M180 cratering kit. An electric blasting cap was inserted into the cap well for firing.

6. The following material is excerpted from DTM 9-1375-213-12-1:

M180 Demolition Kit and Component Dimensions

a. Dimensions, M180 Demolition Kit.

Kit (disassembled and strapped for shipment):

Length------------------------------------39.0 in.
Weight (approx)---------------------------100 lb
Width-------------------------------------11.0 in.
Height------------------------------------16.0 in.

Shaped charge (without fiber base):

Height------------------------------------12.0 in.
Major diameter---------------------------- 7.0 in.

Firing device:

Length------------------------------------ 4.25 in.
Width------------------------------------- 1.25 in.
Height------------------------------------ 3.5 in.

Warhead:

Length------------------------------------29.5 in.
Diameter---------------------------------- 6.5 in.

Rocket motor:

Length------------------------------------18.0 in.
Diameter---------------------------------- 6.5 in.

Demolition Circuit:

Length (overall)------------------------20 ft (approx)

b. Explosives, M180 Demolition Kit.

Weights of explosives (approx):

Shaped charge:

Comp B----------------------------------11.0 lb
Comp A-3-------------------------------- 1.8 oz

Warhead:

H6 high explosive-----------------------40.0 lb

Rocket motor:

Propellant grain M7 modified------------ 5.0 lb

Booster:

RDX------------------------------------- 1.0 oz
Tetryl---------------------------------- 1.0 gr

Demolition circuit:

PETN------------------------------------ 1.0 oz

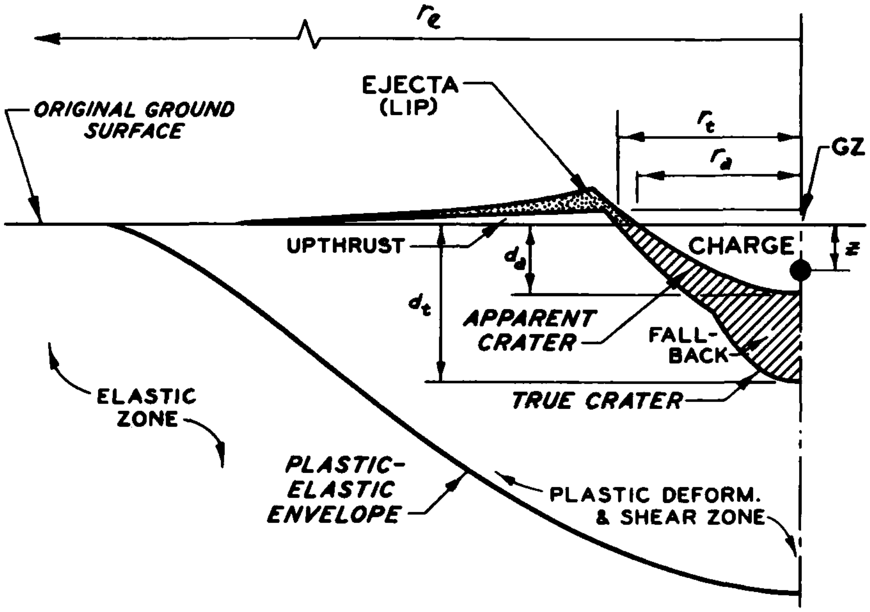
c. Packing, M180 Demolition Kit.

Kits per shipping container------------- 1
Outer dimensions of container (approx)--45-1/2 by 13-1/4 by 20-1/2 in.
Weight of container (w/contents) (approx)---------------------------165 lb
Cubical displacement of container------- 7.2 cu ft

APPENDIX C: CRATER MEASUREMENTS AND TERMINOLOGY

1. As used in this report, a crater is a cavity or void created near the surface of a medium by a compact explosive charge. A ditch is an excavation or elongated cavity resulting from a linear charge. A trench is an excavation constructed by mechanical labor, as the one in which the linear charge is placed.

2. Figure C1 illustrates components of and terminology for a typical explosion-formed crater in soil.



<u>Notation</u>

d_a - apparent crater depth (maximum)

d_t - true crater depth (maximum)

GZ - ground zero

r_a - apparent crater radius

r_e - radius of ejecta deposition

r_t - true crater radius

z - depth of burial (DOB)

Figure C1. Typical crater half-profile and nomenclature for a buried single-charge detonation

3. Figure C2 shows commonly used ditch dimensions and terminology. W_a and D_a are analogous to r_a and d_a in Figure C1; W_{ob} and D_{ob} are the dimensions of more interest in determining obstacle effectiveness. While there is a boundary of undissociated material

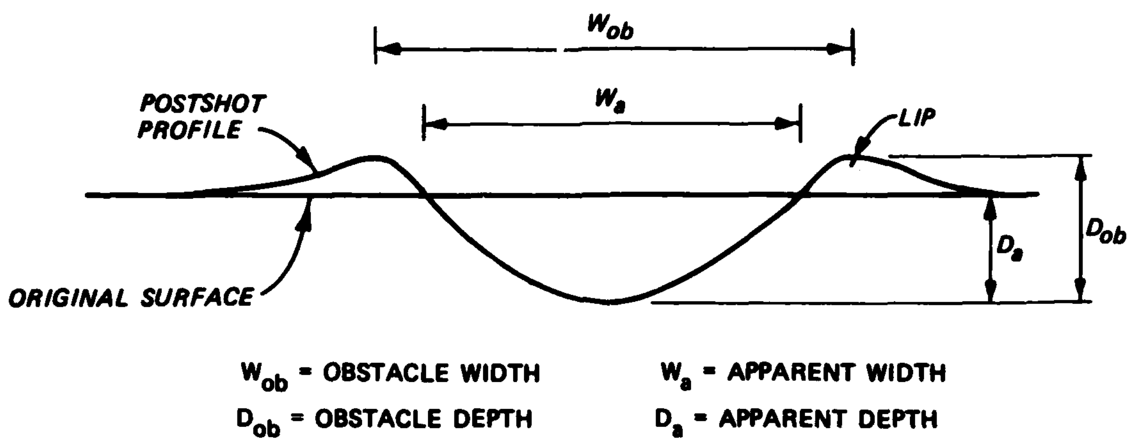


Figure C2. Apparent and obstacle dimensions at ditch cross section. Ditch length L is measured along center line

below the apparent or visible ditch profile, analogous to the true crater boundry, it is not used in this report.

4. Crater dimensions in this study were derived from engineering surveys consisting of tape measurements and differential leveling. Cross sections (XS) were orthogonal to center-line (CL) sections. Ditch CL measurements coincided with the emplacement trench CL. Unless otherwise shown, measurements and dimensions refer to the apparent craters and ditches.

APPENDIX D: ABBREVIATIONS

Commonly Used Abbreviations

APC	Armored personnel carrier
BA	Blasting agent
C4	Composition C4 (a plastic high explosive)
CL	Survey center line
GE	Federal Republic of Germany
HE	High explosive
H6	Main explosion charge for M180 Cratering Kit
ID	Inside diameter
PVC	Polyvinyl chloride
Sta	Survey station
TNT	Trinitrotoluene (high explosive)
XS	Survey cross section

Acronyms (U. S. Army Agencies)

ARRADCOM	U. S. Army Armament Research and Development Command
DARCOM	U. S. Army Materiel Development and Readiness Command
DAEN-RD	Office of the Chief of Engineers, Research and Development Office
TECOM	U. S. Army Test and Evaluation Command
WES	U. S. Army Engineer Waterways Experiment Station
YPG	U. S. Army Yuma Proving Ground

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Woodbury, George A.
  Explosive ditching and pavement breaching tests at Yuma Proving Ground, 1978-1980 / by George A. Woodbury, Jeremiah J. Sullivan, Allen D. Rooke, Jr. (Structures Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1983.
  74 p. in various pagings : ill. ; 27 cm. -- (Miscellaneous paper ; SL-83-10)
  Cover title.
  "June 1983."
  Final report.
  "Prepared for Office, Chief of Engineers, U.S. Army under Project 4A762719AT40."
  Bibliography: p. 65.

  1. Blasting. 2. Cratering. 3. Pavement--Testing. 3. Slurry. 4. Wrecking, Demolition. 5. Yuma Proving

Woodbury, George A.
  Explosive ditching and pavement breaching tests : ... 1983.
(Card 2)

Ground (Ariz.) I. Sullivan, Jeremiah J. II. Rooke, Allen D. III. United States. Army. Corps of Engineers. Office of the Chief of Engineers. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; SL-83-10.
TA7.W34m no.SL-83-10